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MINERALS
AND
HOW TO STUDY THEM

E. S. DANA

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MINERALS,

AND

HOW TO STUDY THEM.

A BOOK FOR BEGINNERS IN MINERALOGY.

BY

EDWARD SALISBURY DANA,
YALE UNIVERSITY, NEW HAVEN,

Author of a Text-book of Mineralogy, Sixth Edition of
Dana's System of Mineralogy, etc.

With more than 300 Illustrations.

SECOND REVISED EDITION
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PREFACE.

THE author has occupied some hours, which could not be devoted to more serious labor, in preparing this little book, in the hope that it might serve to encourage those who have a desire to learn about minerals, and also to increase the number of those whose tastes may lead them in this direction. He shares with most teachers at the present time the conviction that the cultivation of the powers of observation is a most essential element in the education of young people of both sexes; he believes, further, that no subject is better fitted to accomplish this object and at the same time to excite active interest than that of Mineralogy. The attempt has been made to present the whole subject in a clear, simple, and, so far as possible, a readable form without too much detail and at the same time without cheapening the science. As the understanding of the different parts of the subject requires some preliminary knowledge of physics and of chemistry, a little elementary matter in these departments has been introduced.

Much attention has been given to the illustrations, most of which have been made expressly for this book; others (reduced in size) are taken from the sixth edition of the System of Mineralogy (1892); several have been borrowed from Tschermak's Mineralogy, and one from a work by Baumhauer. The correct representation of real crystals and of the actual specimens from the cabinet is a difficult matter, and in this the author has been so fortunate as to secure the services of the skillful wood-engraver Mr. W. F. Hopson of New Haven. Any suggestions which would tend to give this volume greater accuracy or usefulness will be always gratefully received.

New Haven, *July* 1, 1895.

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MINERALS, AND HOW TO STUDY THEM.

CHAPTER I.

MINERALS AND MINERALOGY.

We are to learn about minerals and how to study them; but, before we can fairly begin, we must understand clearly what substances we may call minerals, and what specimens have a right to a place in the collection that every one who wishes to become a mineralogist must make.

We all know, in the first place, that minerals are the materials out of which the earth is built, and we often hear that division of nature to which they belong called the *Mineral Kingdom,* in distinction from the Animal and Vegetable Kingdoms, which embrace the animals and plants which live and grow upon the earth's surface.

And here it is important to realize how little we can know by actual contact and direct observation about this earth, though we live upon it. It is possible, indeed, to measure its size and shape, to find out its density as a whole, to study its surface features and the changes which they have undergone; but of the materials of which it is made we can know little beyond those which form the surface upon which we walk. The miner digs down a little distance, and the artesian-well borer goes down still deeper, and we may have a chance to examine the specimens that their work brings up; or perhaps we can go down with the miner and see them in place. But the deepest mines descend to less than three quarters of a mile, and though this seems deep to one who is let down a shaft in a bucket, it is but a little way compared with the whole distance to the earth's center, which would require a journey of nearly 4000 miles. Even the deepest artesian-well borings hardly go down to the depth of one mile.

Our knowledge, to be sure, is increased a little by the fact that we find now on the surface of the earth rocks made, as we have reason to believe, of materials brought up in a molten condition from great depths below. This is true of the lava thrown out by a volcano, and of such igneous rocks, for example, as form the Palisades along the Hudson River; and these occurrences give us some idea as to what kinds of matter there are, and in what condition, far below the surface. Further, we are able to weigh the entire earth, too, and find what its density is; and as this is nearly twice as great as that of the rocks on the surface, it gives a suggestion as to the heavy nature of the mineral material that must make up the interior.

Thus the mineralogist is limited to the study of the little part of the crust of earth which he can reach with his hammer; and he cannot extend his collection much beyond this, unless indeed he takes in some of those rare visitors from outer space—called *meteorites*—which once in a while tumble down to the earth, usually with a bright light and loud explosion.

Now what does this study show of the hard rocky material of which the earth, so far as we can examine it, is made up; for example, of the sand of the seashore, the granite, the trap, the slate and marble of the hills?

We find, in the first place, that it in general consists of different kinds of substances, each one having certain peculiarities or characters of its own, by which it can always be recognized; and it is to each of these individual kinds that the name MINERAL is given.

Thus, more particularly, the sand of the seashore can be separated without much difficulty into various sorts of grains, each kind alike in chemical substance, as the chemist can prove in the laboratory, and with certain characters of hardness, density, luster, and color of its own, which enable us after a little practice to distinguish the different kinds with comparative ease.

Most of the grains are alike clear and glassy, hard enough to scratch glass, and as we learn to know them better we call them *quartz*. There are also black grains; some of these are heavy and jump to a magnet, and often they are sorted out by the waves into little rifts on the white sand; these are called *magnetite*, or magnetic iron. There are other black grains, too, which the magnet does not attract, perhaps some red, glassy ones which are fragments of *garnets*, and, it may be, still others, depending upon where the sand comes from, and what kind of rock has been ground up by nature's mill and sorted out by the water to make the sand.

If a piece of granite is taken, here too it is possible to distinguish several kinds of mineral substances, though it is not quite so easy to separate them. There are hard glassy grains with irregular surface, which, like the greater part of the sand-grains, are *quartz*. There are white or yellow or pale flesh-red fragments, also hard, though not so hard as the others, but which are sure to show one or two smooth surfaces of fracture: these are *feldspar*. Then there is the *mica*, more easily recognized still, which is either nearly white and silvery, or black (and sometimes both kinds), and which with a touch of the knife separates into very thin scales or leaves. Besides these there may be a little coal-black tourmaline, some bright red garnets, and other kinds which we shall learn later. If a cavity or open space in the granite can be found, here it is often possible to find the same kinds of substances, only larger and more distinct and very likely in the regular form which are called crystals.

If, instead of a coarse-grained rock like granite, we examine a fine compact one such as the trap-rock of the Palisades on the Hudson, it very probably appears all alike to the eye; but if we crush some of it to powder, the magnet will pick out some magnetic iron, as from the seashore sand. Or the skillful mineralogist may make a slice thin enough to be transparent, so that he can study it under the microscope, and then recognize a variety of different minerals. In seams and cavities in these rocks other sorts are often found, not like those in the solid rock.

Sometimes we find a rock, like the white marble of Vermont, which the examination of the chemist shows to be all of the same chemical substance, and which has throughout the same characters of hardness, density, color, and so on; then it is said to be a mineral itself, and not, like most rocks, a mixture of a variety of different minerals.

These different kinds of substances, then, which make up the rocky material of the earth so far as we can study it, and into which we can separate the seashore sand, the granite, and most other rocks, are called MINERALS. Each one has, first of all, a definite chemical composition, wherever it is found. Moreover, if in the form of a crystal, it has a shape of its own, too, by which it may be distinguished; it has also certain characters of hardness and density, luster, color, transparency, and others. And because to it belong all these different characters, which distinguish it from other kinds, it is called a MINERAL SPECIES.

It is the work of the mineralogist to study these minerals; to learn all the different kinds; what the characters of each are; how they are classified and how distinguished from each other; how they occur in nature; and something about their practical uses.

All the knowledge which the many mineralogists have learned, after long years of patient observation and study, both in the field and the laboratory, has been arranged in systematic form and makes up the *Science of Mineralogy.*

The question as to what particular minerals go together to make the different kinds of rocks, how these are formed, and what changes of position or of character they have experienced—all these and other similar questions are referred to the geologist. The science of the geologist, or geology, is much broader than mineralogy: it treats of the history of the earth and all the changes it has gone through; the different kinds of rocks; the way the mountains have been built up from them; the growth and development of different kinds of life from the earliest times down to the present.

It was stated at the beginning of the chapter that minerals belong to the MINERAL KINGDOM; but it is important to remember that all substances mineral in nature are not necessarily called minerals.

The mineralogist, for example, usually excludes from his cabinet many mineral substances, such as the pearl of the oyster-shell and the shell itself, the lime of the bones of animals, and the opal-like form of silica secreted by the growth of plants, as the tabasheer found in the joints of the bamboo. In general mineral substances such as these, which are formed immediately by the processes of animal or vegetable life, are not called minerals.

Further, the mineralogist does not, as a rule, admit among minerals gases like the oxygen and nitrogen which make up the air; and of the liquids he includes only the metal mercury, and perhaps also water.

The many beautiful kinds of salts made by the chemist are also not called minerals. The rock salt or sodium chloride which is mined, sometimes in fine clear cubical blocks, is the same sodium chloride which, as the table-salt of every-day life, is so commonly used. But the table-salt obtained from evaporating sea-water or the brines of salt-wells, or from the solution of crude rock salt, though when manufactured it may be formed in crystals as fine as those found in the rocks, is not called a mineral, because not made by nature alone. So, too, the fine crystals of blue vitriol, or copper sulphate, made by the chemist, do not find a place in a mineral cabinet, though the much less fine specimens of the same material found in some of the Arizona mines do. In the same way, the crystals of the metals and of many interesting compounds formed in the metallurgical process of making iron or lead or zinc are called *furnace-products*, and not minerals. These substances, however, are all very interesting, and their study is a very important help to pure mineralogy. In recent years the chemist has busied himself in imitating, so far as he can, the possible processes of nature, and thus making "*artificial minerals.*" Recently the diamond has been formed in minute crystals, also small but fine clear rubies, and so, too, quartz, feldspar, mica, and many common species.

It must be acknowledged, however, that the specimens thus obtained in the laboratory are in most cases very minute and much less beautiful than those of nature; for the chemist in the laboratory has only a limited time for his experiments, and often must use violent means,—as the great heat of a furnace,—while nature works slowly and gently.

CHAPTER II.

SOME PRELIMINARY HINTS AS TO HOW TO STUDY MINERALS.

A MINERAL, we have seen, is a substance formed by nature alone, a solid with one or two exceptions, and one having as a rule a definite form of its own and certain characters of hardness, density, luster, color, and still others, and, most important of all, a definite chemical composition. The first group of characters, having to do with the form and structure and so on, are called PHYSICAL CHARACTERS, while those depending directly upon the composition are called CHEMICAL CHARACTERS. All of these will be described in some detail in subsequent chapters, but it is necessary first to gain a little knowledge as to how to study minerals, where the object is to learn as much as possible about each and to distinguish one kind from another.

The mineralogist must first of all use his eyes and other unaided senses in studying minerals; in other words, he must gain all the information he can about minerals by looking at them and handling them. If he learns to do this wisely, he will be surprised to find how keen his senses become and how much he can find out. But as he gains in experience he will see that this only carries him to a certain point, and he should always recognize the importance of confirming the conclusions reached by his eye and hand by more positive tests. Often, even in the case of the commonest species, the appearance may lead one who depends upon it alone quite astray. The old saying that "all is not gold that glitters," and the names applied to certain common minerals of "fool's gold," "false galena," and others like them, express the result of experience that the senses unassisted may readily be deceived.

The trained eye of the mineralogist will show him, first of all, the *form* of the mineral, as to whether it has the regular geometrical shape of a crystal or not, or is simply granular, fibrous, and so on. It will show him whether it has the natural, easy, smooth fracture of many crystallized substances, called *cleavage*, or only the fracture of ordinary kinds. It will tell him, too, what peculiarities of *luster* the surface of a mineral presents, depending upon the way in which it reflects light, whether metallic, glassy, greasy, or silky, and so on; also what the *color* is, whether it is transparent or opaque, and many other points.

The *touch* will show whether the "feel" is greasy, as is true of a few very soft minerals, or harsh, as are the majority. Again, a mass in the hand will often be recognized at once as heavy or light as compared with familiar substances of the same appearance. Thus the common minerals quartz, feldspar, calcite, have nearly the same density, and one can easily become so accustomed to them that a piece of gypsum seems light and one of barite (heavy spar) seems heavy. So a piece of the metal aluminium seems very light because we instinctively compare it with the other much denser metals which we are accustomed to handle.

The *taste* may sometimes tell, for instance, that rock salt is in hand, while the *odor* is occasionally a useful character, as the clayey odor of some minerals when breathed upon.

But it requires some education and experience before the senses are so on the alert that all the characters noted are perceived at once and rightly estimated; this is what every one should strive for; and one of the great benefits to be derived from the study of mineralogy is that it cultivates and stimulates the powers of observation.

When the senses alone stop, simple tests to aid them come in. A touch upon the smooth surface of a mineral with the point of a knife serves to show whether it is relatively soft or hard. The color of the powder obtained by scratching with the knife or upon a plate of rough porcelain or ground glass, called the *streak*, is sometimes quite different from that of the surface, and in such cases this is a very important character.

Then come more careful tests: the determination of the relative density or specific gravity; the use of the blowpipe, giving the comparative degree of fusibility; and a number of simple chemical trials, to show the presence of sulphur or arsenic, silver, lead or iron, barium or strontium. Then follow still other tests, till we come to the refined methods of the trained mineralogist with his beautiful goniometer for measuring angles, the microscope and optical instruments, the accurate chemical analysis and other means by which most of nature's secrets may be learned and the characters of each mineral thoroughly studied.

SOME SUGGESTIONS ABOUT MAKING A COLLECTION OF MINERALS.

A very important matter in the study of minerals is the student's own collection; for every one who desires to really learn mineralogy must have a collection of his own to examine and experiment upon. It is very desirable that the school or college should have a larger cabinet for reference and study, but this does not take the place of the individual collection, which will be studied, arranged, labeled, and handled over and over again till every specimen is perfectly familiar.

Further, the student should obtain his specimens as far as he can by collecting for himself. No matter if he lives in a region that does not seem at first to afford very much, he can certainly find something that is worth keeping until he obtains better; and occasionally he will have the opportunity to make trips to some of the noted localities, where he can find more and a great variety. There is nothing more delightfully instructive and health-giving than to spend a day in the open air, with a good hammer in hand, a bag for the specimens, and plenty of soft paper (and perhaps some cotton) to wrap them up in.

The hammer should be of hard steel that will not chip on the edges; it may weigh from a pound to a pound and a half, and the face should be square or slightly oblong and the edges sharp, while the back has the form of a wedge, as seen in Figure 1 (one-fourth natural size). A cold-chisel or two, for working into cracks or crevices, will often be found useful; also a small light hammer with a sharp edge for trimming specimens. This will often do no damage, when a blow from a heavy hammer would shatter the specimen and destroy it. .

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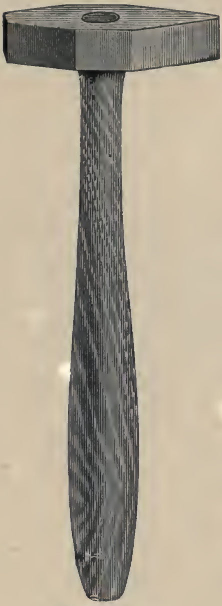

¼ natural size.

Do not break the crystals out of the rock, as a rule. A detached crystal of garnet is interesting when quite perfect, but in general the crystal is most interesting and instructive when in its own home. The seller of minerals soon discovers this, and it is unfortunately not an uncommon trick at some localities—for instance in the Alps—for the local collector working for his daily bread to exercise his ingenuity in mounting a loose crystal in a mass of rock in which it never belonged, thus to increase the value of the specimen and deceive the unwary purchaser.

The student is not advised to spend a great deal of money in buying specimens, particularly at any one time. Still it is less easy to collect personally now than it was years ago, and many students may not have opportunity to do the traveling that it requires: and even here the reward is often small, unless at a quarry or mine where work is being carried on all the time.

Hence a little money is by no means thrown away if judiciously expended from time to time, for it will serve to buy a few small characteristic specimens of the common species and pure fragments for blowpipe tests. Fine specimens, especially of the rarer species, are now very expensive, but sufficiently good ones of the minerals it is important for the student to know well may be obtained, for very little money.*

It is better to collect small specimens rather than large, as far as possible, such as will go in a little paper tray 2 inches square, or 2 by 3 inches, or at most 3 × 3. These trays are inexpensive and are very useful for the arrangement and preservation of a cabinet. If the specimens are placed loose in a drawer, it can hardly be opened a few times without throwing them into confusion, and sooner or later they will be badly injured. The sizes mentioned are the most useful, though 3 × 4 inches might well be added. A depth of half an inch is sufficient for the tray, but the drawers, if possible, should not be less than 2½ or 3 inches deep. All the specimens in a collection should be carefully labeled, particularly as regards the *locality*.

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* A list of the most important minerals is given at the close of the book, and those most useful for trial with the blowpipe are there indicated.

CHAPTER III.

THE FORMS OF CRYSTALS AND KINDS OF STRUCTURE.

The principal characters of minerals, by which one species is distinguished from another, have been briefly alluded to in the preceding chapter. It is now necessary to study some of these characters more fully.

First the Physical Characters will be considered. These include the form and structure, the cleavage, fracture, hardness, tenacity, elasticity; also the density; further, the color, luster, degree of transparency, and some few others. The present chapter is limited to a discussion of the crystalline form and the structure in general.

The General Characters of Crystals.

If we examine the specimens of the different mineral species in a good cabinet, we see that many of them occur commonly in regular solid forms with smooth faces, which forms, as we study the subject further, we find to be characteristic of each individual species. These regular forms are called *crystals*. The cubes of fluorite (Fig. 2) or galena, the six-sided prisms of quartz (Fig. 3), the twelve-sided, twenty-four-sided, or even more complex forms of garnets, are common examples of crystals. Further, even when a specimen does not show this regular external form, there is usually a definite crystalline structure, which may be shown in the easy fracture called *cleavage*, as that of calcite, or which may be indicated in other ways, as we shall soon learn. How is this regularity of form and structure to be explained? First, we will speak of crystals.

The physicist, as the result of his studies into the structure of different kinds of matter, has concluded that every body is built up of minute particles called molecules, which are much too small to be perceived even by the strongest microscope. In a solid body, as a lump of iron, ice, sulphur, he thinks of these molecules as bound together by a strong force of *attraction*, called cohesion, so that it requires a hard blow or great pressure to change its shape. In a liquid body he thinks of them as free to move or roll over each other, so that the liquid takes at once the shape of the vessel in which it is contained, whatever that may be. In a gas, he believes that the molecules are sepa-

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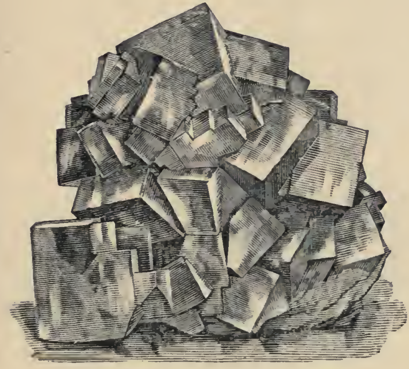
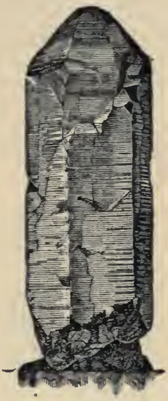


Fluorite, Group of Cubic Crystals.

3.



Quartz Crystal.

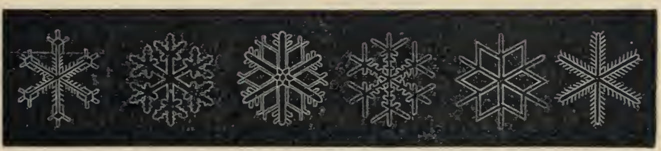
rate from each other, a long distance in fact compared with their size, and that they are darting about very rapidly, colliding against each other and any confining surface. The result of this is that the gas at once fills entirely a vessel into which it is introduced and presses against its sides; the pressure being simply the result of the bombardment of these little rifle-balls. The pressure of the external air, for example, is shown by the collapse of the cheeks when the air within the mouth is drawn away.

The relation between these minute particles or molecules, thus explains the condition of a body, as solid, liquid, or gaseous; for example, the distinction between ice, water, and steam.

But more than this: When a liquid turns into a solid because the temperature falls, as when water freezes, or liquid sulphur or molten iron hardens on cooling, the force of cohesion comes into play to bind the particles together into a rigid mass. So, also, when by slow evaporation from a solution, as of salt or alum in water, the dissolving liquid is removed, the substance in solution also passes back into the solid form under the action of this same force of cohesion. Thus the solid is formed from the liquid by the action of the forces acting between these little particles. Further, if the molecules are all of one kind, as in a given chemical substance, and if there are no hindering causes, these molecules will build themselves up after some regular pattern and the external result is the geometrical form, which is called a crystal. It is somewhat as if the molecules were little building-stones, built up into a solid structure by forces acting between them and causing them to arrange themselves after a definite manner when they are free to do so.

This regular building of the molecules, which, as has just been shown, may take place from a liquid, happens also, even more perfectly, when a solid is formed direct from a gas. Water vapor in the air, if cooled down sufficiently, is formed into the solid snow, and the little snow-crystals, that fall silently through the atmosphere and which we may catch on our coat-sleeve on a cold winter day, are often of wonderful regularity and beauty of form. The figure (4) gives some of the many forms of snow-crystals drawn by Scoresby in a visit to the Arctic many years ago. So too, as will be described later, if a mineral containing arsenic is heated in a glass tube open at both ends, the arsenic driven off, uniting with the oxygen of the air, forms the vapor of oxide of arsenic; this is condensed a little higher in the tube, where it is cooler, and there deposited in minute spangling octahedral crystals (Fig. 6, p. 23), which are sometimes quite large and very perfect in form.

4.



Snow-crystals.

It is not always easy to make good crystals, whether starting from a liquid or from a gas. This is true in part because we cannot give the time required for the perfect process, in part because there are other hindering conditions. But sometimes we can succeed well, and the growth of an octahedral crystal of alum in a strong solution can be watched from day to day and a large and fine crystal may be the reward of our skill and patience.

In nature's laboratory the conditions are more favorable, particularly because there is never any limit of time, and the many beautiful and complex crystals of minerals with brilliant faces show the result. Even here, however, the building process often cannot go on freely, and imperfect crystals, or perhaps a mass with only a confused crystalline structure and without distinct external form, may be all that is produced.

The quartz, feldspar, and mica in the rock called granite have usually formed together in such a way that neither one has had an opportunity to build itself up into perfect crystals, and yet the student who understands the optical study of thin sections of a rock in polarized light can prove that each grain, formless though it may be externally, has all the internal molecular structure of the crystal. In a cavity in the granite we are not surprised to find crystals of quartz and feldspar, perhaps also of mica, as the cavity here means that each has had an opportunity to exercise its tendency to build itself regularly with something of the freedom which a perfect crystal requires.

Another familiar example of crystallization is given by the ice covering a pond, which is as truly crystalline in structure as the perfect snow-crystal; but here there are no crystals, and it is easy to understand why. The slow dissection of the mass, however, under the melting action of the sun reveals something of the regularity in the molec ular building, and the same thing is proved by an examination in polarized light. Sometimes in the freezing of a little pool of water on a sidewalk the formation of the slender crystalline ribs of ice may be watched as they shoot out, forming a framework which may soon lose its distinctness as the entire surface is frozen over.

We learn, then, that a crystal is the regular solid form which a chemical substance takes when it passes into the solid state from that of either a liquid or a gas, if under such conditions that the molecules are quite free to arrange themselves according to the direction of the attractive forces acting between them.

The crystal is, therefore, the *outward* expression of the structure in the arrangement of these molecules, and its form is for this reason the most important of all the physical characters of a given species and the one which in general most definitely distinguishes it from others.

It is interesting to note that a small crystal is just as perfect and complete an individual as a similar one of great size; there is among the crystals of a given species no such connection between size, on the one hand, and age and maturity, on the other, that belongs to the individuals of a species in the animal and vegetable kingdoms. Some crystals are so minute as to be almost microscopic; others may be of enormous size, as the gigantic quartz crystals occasionally found in the Alps, or the equally large beryl crystals from New Hampshire. A cave opened a few years ago at Macomb, New York, contained 15 tons of great cubic crystals of fluorite; another cave in Wayne County, Utah, contained a great number of enormous crystals of gypsum, some of them three feet or more in length. But the very small crystals and the like ones of enormous size are not essentially different except in this comparatively unimportant respect of magnitude.

And yet there are many interesting points of resemblance between crystals and living plants. Crystals *grow* as well as plants, and under favorable conditions so rapidly that the increase in size may be watched not only from day to day, but from hour to hour, or even from minute to minute. The complex forms that are built up especially in such cases of rapid growth are often wonderfully plantlike in aspect. This is true, as every one has noticed, of the delicate frost-figures which form so quickly upon a window-pane or a paving-stone in winter; also, in other more permanent cases, the arborescent or dendritic forms of native gold or silver or copper are good examples of the same fact. The terms used in describing them are indeed given because of their resemblance to forms of vegetation. Furthermore, as a wounded plant tends to heal itself when, for example, a branch has been broken off, or as a slip or graft tends to develop a full individual; so, too, a broken crystal may be more or less healed, but in the last case the material which repairs the injury must be supplied from an outside source. Thus the silica to mend a broken quartz crystal must come from a foreign solution, and the crystal itself only directs the way in which the molecules of the solution are laid down; it is interesting, however, that the growth takes place more readily on a surface of fracture than on a natural crystalline face. In this way the grains of quartz in a sandstone, formless because only fractured fragments, often tend to build themselves up into complete crystals.

Still again, although a crystal never has an old age in the sense that this is true of a plant or an animal, it is nevertheless a fact that many crystals tend to change or decay as time goes on, if subjected, for example, to the corroding effects of some foreign solution.

Even the beautiful gems, such as the sapphire, emerald, topaz, garnet, hard and comparatively insoluble as they are, have this liability to undergo what is called chemical decomposition, with the loss of all their beauty and a total change of chemical substance. This is spoken of again in a later part of the chapter, where pseudomorphs are described, but it is worth noting here because somewhat analogous to the change that old age brings to a living organism.

THE SYSTEMS OF CRYSTALLIZATION.

The forms of crystals are so varied and the difficulties in studying them minutely so great that we shall only attempt here to learn some of their simplest kinds. In the first place, it is important to understand that it can be shown that all crystals belong to one of six classes, or systems, which are named as follows: I, ISOMETRIC; II, TETRAGONAL; III, HEXAGONAL; IV, ORTHORHOMBIC; V, MONOCLINIC; VI, TRICLINIC.

The characters of each system and the relations between them will be briefly mentioned after the chief forms in each have been described.

I. *Isometric System.*

The principal forms of the Isometric System are the cube, octahedron, dodecahedron, the two trisoctahedrons, the tetrahexahedron, and the hexoctahedron.

5 *Cube.*—The cube has six equal faces, each one of which is a square, and the angle between any two faces is a right angle, or 90°. It is shown in Fig. 5. Galena and fluorite often occur in cubes.

6 *Octahedron.*—A regular octahedron (Fig. 6) has eight like faces,* each a triangle with equal sides and three equal angles (each 60°); the angle between any two adjacent faces is 109° 28′. Magnetite is often in octahedrons.

Dodecahedron.—The rhombic dodecahedron (Fig. 7) has twelve equal faces,* each of which is a rhomb with plane angles of 60° and 120°, while the angle between two adjacent faces is 120°. This is a common form with garnet.

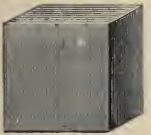
These forms may occur together on the same crystal. Thus crystals of galena often show the cube and octahedron together. Fig. 8 is generally described as a cube modified by an octahedron, and Fig. 9 as an octahedron modified by the cube. If a cube is cut out of a block and the solid angles sliced away carefully, the new surface making equal angles with the three cubic faces, the result is to give finally an octahedron. It is seen that the octahedral faces are little triangles on the solid angles of the cube and equally inclined to the three cubic faces. On the other hand, the cubic faces are small squares on the six solid angles of the octahedron. The angle between two adjacent faces of a cube and an octahedron is 125° 16′.

---

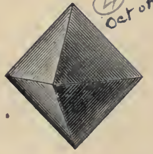
* Octahedron is named from the Greek ὀκτώ, *eight*, and ἕδρα, *face*, or the *eight-faced* solid. Dodecahedron is similarly named from δώδεκα, *twelve*, and ἕδρα, *face*.

Figures 10, 11 show the cube and dodecahedron together, and Fig. 12 the octahedron and dodecahedron. Both the cube and octahedron have twelve similar edges, and these are cut off equally, or *truncated*, by the twelve faces of the dodecahedron. In Fig. 13 we have again a form (not shaded) resulting from the combination of the faces of the cube (a), octahedron (o), and dodecahedron (d). The angle between adjacent faces of the cube and dodecahedron is 135°; between those of the octahedron and dodecahedron it is 144° 44′.

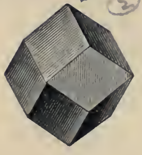
5. ①



6. ④ Octohedron



7. Dodecahedron ②



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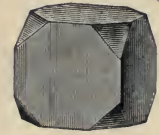

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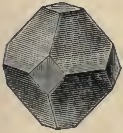

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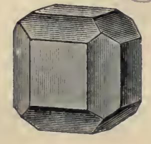

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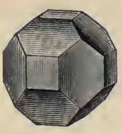

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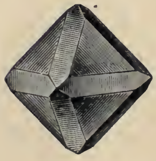

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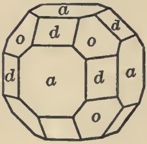
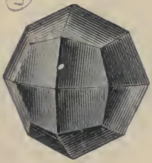


Trapezohedron.—A trapezohedron has twenty-four equal faces, each a four-sided figure or trapezoid. It is shown in Fig. 14, which is a common form with garnet. There may be a large number of different trapezohedrons, all having the same general form but differing in the angles between the faces. A similar remark may be made about each of the other type-forms of this system yet to be described. It requires much more study than is possible for the beginner to learn how these forms are mathematically distinguished from one another.

14.

③

Trapezohedron.



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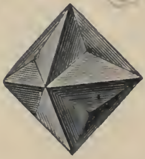
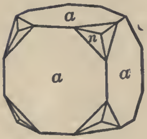


Figures 16 to 19 show combinations of the trapezohedron (*n* or *m*) with the cube (*a*), octahedron (*o*), and dodecahedron (*d*). The last two are common forms with garnet.

16.



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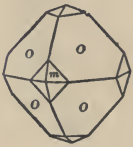

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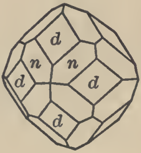

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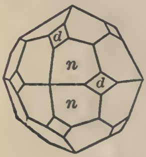
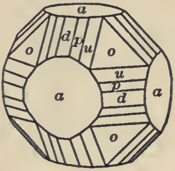


The trapezohedron is also called a tetragonal trisoctahedron because its form suggests an octahedron in which three faces take the place of a single octahedral face, each of them being a four-sided figure or tetragon.

There is also another trisoctahedron, called a trigonal trisoctahedron, shown in Fig. 15, which has, again, twenty-four faces, three of these also corresponding to an octahedral face; but each is a three-sided figure (trigon) or an isosceles triangle. This form does not often occur alone, but may be seen on complex crystals of galena. Fig. 20 shows a figure of galena with the cube (*a*), octahedron (*o*), dodecahedron (*d*); also two different trigonal trisoctahedrons, lettered *p* and *u*.

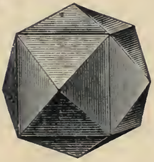
20.



Tetrahexahedron.—A tetrahexahedron (Fig. 21) is a twenty-four-faced solid,* each face an isosceles triangle and four together having the same position as the face of a cube. Fig. 22 shows a combination of the cube and a tetrahexahedron; the latter is said to *bevel* the edges of the cube because the two planes are equally inclined to the two adjacent cubic faces.

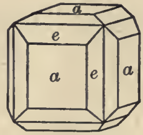
Tetrahedron

21.



⑥

22.



Hexoctahedron.—A hexoctahedron (Fig. 23) is a forty-eight-faced solid; each face is a scalene triangle, and six faces have the same general position as a face of an octahedron.†

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* Named from τέτρα, *four*. εξ, *six*, and ἕδρα, *face*.

† Named from εξ, *six*, ὀκτώ, *eight*, and ἕδρα, *face*.

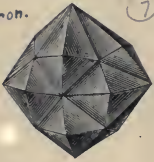
Fig. 24 shows a combination of the cube (*a*) with the hexoctahedron; it is a common form with fluorite. Fig. 25 is a common garnet form, the dodecahedron (*d*) with the hexoctahedron, the latter beveling the edges of the former.

Many of the figures thus far given and some of those which follow are shaded, so as to appear *solid* to the student learning about crystals for the first time. It is obvious, however, that when the form is complex that the shading is impossible, and for the experienced crystallographer it is quite unnecessary; hence these more complex figures are shown in line only. Through the rest of the book these line figures will be freely used. The student will soon find that they appear as solid to him as the others.*

23.

Hexoctohedron.

⑦



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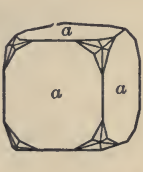

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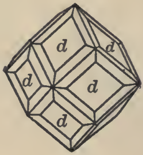

All the forms that have been mentioned belong to what is called the ISOMETRIC SYSTEM, in which the crystallographer refers the planes to *three equal axes at right angles*

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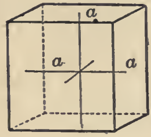
* It will be a great help to the student if he has a few models to handle. These are made in great perfection in wood and are not very expensive. The student may also try to cut them for himself out of soft wood or plaster-of-paris; even a potato can be employed for temporary use.

to each other. The position of the axes passing through the centers of the crystals is shown in Figs. 26, 27, 28.

26.



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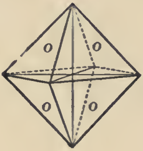

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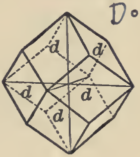

Dodecahedron.

It will be seen to be true of all these, as it is of all their combinations, that the arrangement of the faces is the same about each one of the six cubic faces, or in other words about the ends of the three axes.

Another way of stating this is to say that all these isometric crystals have three equal planes of symmetry at right angles to each other.* These three equal planes of symmetry are planes parallel to the cubic faces and have a corresponding position in the other simple crystals or combinations of them. Each plane of symmetry divides the ideal crystal into two symmetrical halves, and here the three sets of halves made by the three planes parallel to each pair of cubic faces are identical; hence the planes of symmetry are said to be equal. The axes are the lines in which these three planes of symmetry intersect each other.

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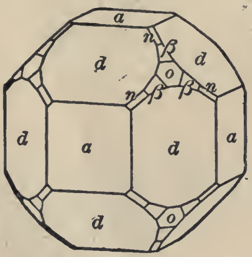
* A plane of symmetry is a plane which divides the solid into equal halves such that if one half is placed against a mirror the reflection completes the form. This is one form of the geometrical definition applying to an ideal crystal; it will be explained later (p 50) how this must be broadened to cover the crystallographic symmetry of actual crystals.

A cube, as well as the other isometric forms mentioned, has also six other planes of symmetry passing diagonally through the opposite edges, and hence parallel to each pair of the dodecahedral faces.

29.



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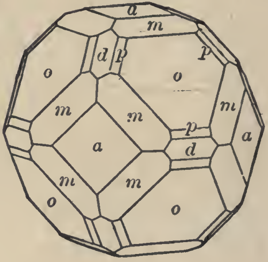


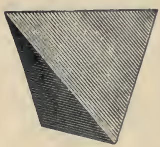
Fig. 29, of cuprite, and Fig. 30, of the rare species microlite, both drawn on a larger scale, are added to show some rather complex combinations of isometric forms. In Fig. 29 the cube (*a*) and the dodecahedron (*d*) predominate; the faces of the octahedron (*o*) are small; *n* and *β* are faces of two different trapezohedrons. In Fig. 30 the octahedron (*o*) predominates and then the cube (*a*), while the dodecahedron (*d*) is subordinate; the faces *m* belong to a trapezohedron, and *p* to a trigonal trisoctahedron.

There are also several other forms belonging to the Isometric System, but which are described as half-forms, or forms in which only half of the faces in the corresponding whole form are present. To them the rules of symmetry do not apply, but their faces are also referred to three equal axes at right angles to each other. The most important of these half-forms are the tetrahedron and pyritohedron.

Tetrahedron.—The tetrahedron (Fig. 31) is a form with four equal triangular faces, each of them an equilateral triangle. It is considered in Crystallography as the half-form of the octahedron, since half the faces of the octahedron, taken every other one, will if extended form a tetrahedron. Perhaps a study of Fig. 32 will make this clearer. The angle between two adjacent faces of a tetrahedron is 70° 32′.

31.

(a)



32.

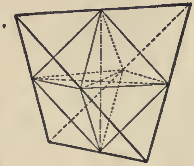
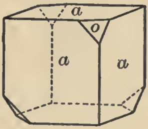


Fig. 33 shows a combination of a cube (*a*) with the four faces of a tetrahedron (*o*). It is seen that the planes are present only on the alternate angles of the cube. In Fig. 34, a combination of a cube and a tetrahedron, the latter predominates. Fig. 35 shows a combination of the tetrahedron before figured (*o*) with another similar form (lettered o_1) made up of the four remaining faces of the octahedron. It might be asked why this form cannot be regarded as an octahedron in which four faces are ac-

33.



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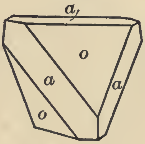

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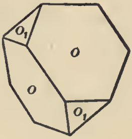
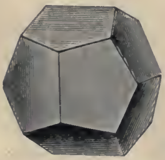


cidentally larger (compare remarks on p. 49) than the others; but this is impossible, for it can be proved, perhaps at once by difference of luster, that the eight faces are not *all* alike, but only four and four. This, however, is a somewhat difficult subject for a beginner.

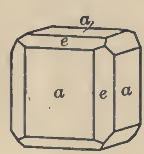
Pyritohedron.—The pyritohedron (Fig. 36) is a twelve-sided solid, or dodecahedron, each face of which is a pentagon, but not here as with the pentagonal dodecahedron of geometry a regular pentagon. In crystallography the name dodecahedron is usually given only to the rhombic dodecahedron described above (Fig. 7), and this form, the pyritohedron, takes its name from the species pyrite or iron pyrites, because of common occurrence with it.

36. ⑤



The pyritohedron is the half-form of the tetrahexahedron. If in combination with the cube, the solids in Figs. 37, 38 result; Fig. 39 is a combination of an octahedron and pyritohedron. There are also other half-forms in the Isometric System, thus of the two trisoctahedrons and the hexoctahedron; but they are not very com mon and will not be described here.

37.



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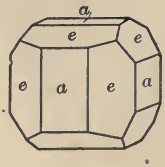

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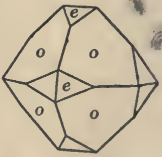
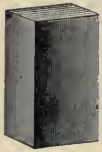


II. *Tetragonal System.*

The chief forms of the Tetragonal System are the two square prisms and pyramids and the eight-sided prism and double eight-sided pyramid.

40.



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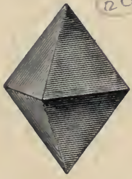

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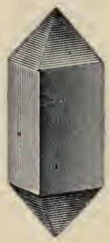


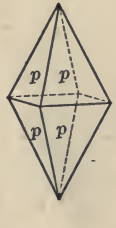
Square Prism and Pyramid.—One of the square prisms is shown in Fig. 40 and the square pyramid corresponding to it in Fig. 41, while Fig. 42 is a combination of the two forms.

The square prism has, like the cube, angles of 90° between the faces, but it differs from the cube because the four vertical faces are not like the two end faces, or *basal planes* as they are called. This is often shown in a crystal by the difference in the smoothness of the two kinds of faces; or there may be easy fracture, or cleavage, parallel to one set of planes and not to the other.

The square pyramid looks somewhat like a regular octahedron, but here the faces are isosceles triangles (not equilateral) and the angle between two faces over a horizontal edge differs from that over one of the vertical edges—in fact, either angle is characteristic of a given species and differs from one species to another. There may be a great many square pyramids of the same type as this but differing in their angles and consequently flatter or sharper at the extremity.

Fig. 43 shows an acute square pyramid, *p*, while Fig. 44 represents another crystal of the same species (octahedrite) in which this pyramid *p* is present but with it three others, *z*, *i*, *v*, each flatter or more obtuse at the summit than the others.

43.



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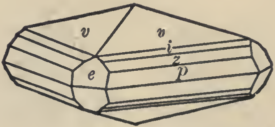
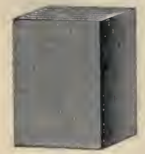
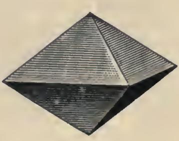


There is also another square prism and another square pyramid diagonal to the set just described; they are shown in Figs. 45 and 46. Fig. 47 shows these two forms together. Taken alone these two forms cannot be distinguished from the other two shown in Figs. 40, 41, but

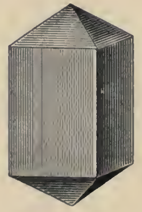
45.



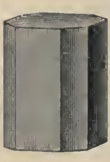
46.



47.



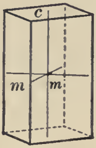
48.



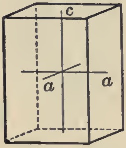
if they occur together the distinction is obvious. Thus Fig. 48 shows the two prisms on the same crystal, the faces of one truncating the edges of the other.

Figs. 49 and 50 show the same two prisms in skeleton lines with the axes represented inside; it is seen that in the prism (Fig. 49) first mentioned—often called the unit prism—the horizontal axes join the middle points of the opposite edges, while in Fig. 50 they join the centers of the opposite faces. The latter form is often called the diametral prism, because the faces are parallel to the axes or diameters.

49.

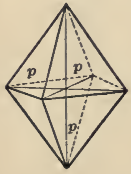


50.

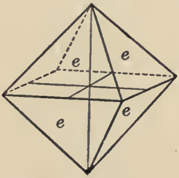


In Figs. 51 and 52 the two pyramids are again shown, and here the position of the axes should also be noted. Fig. 51 is often called a unit pyramid or one of the unit series; Fig. 52 a pyramid of the diametral series.

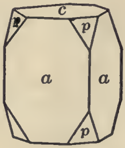
51.



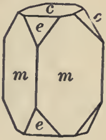
52.



53.

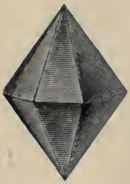


54.



In Figs. 53, 54 the combinations of each square prism with the pyramid of the diagonal set are shown. Fig. 53 resembles a cube modified by an octahedron (Fig. 8, p. 23), but it differs from it in that the faces lettered *p*, while they make equal angles with the two adjacent faces *a*, make different angles with the basal plane or base *c*. The same statement could be made in regard to the form of Fig. 54.

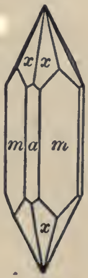
55.



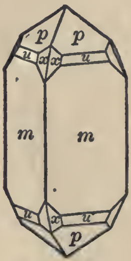
There is also an eight-sided prism made up of eight like faces, and it is shown on the complex crystal represented in Fig. 59; its faces are lettered *h*. Further, there is also a double eight-sided pyramid, as shown in Fig. 55. This is often called a *zirconoid,* because common with the species zircon.

In Figs. 56, 57, 58, representations of crystals of zircon, the faces *x* (in part lettered) belong to a zirconoid or

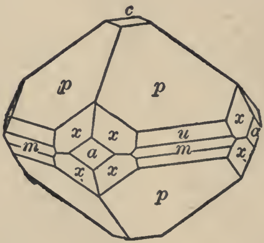
56.



57.



58.



double eight-sided pyramid. The same is true of the faces lettered *z* in the figures 59, 60.

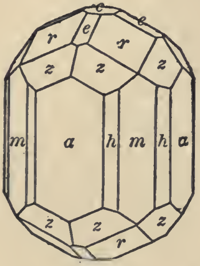
Fig. 59 represents a complex crystal of wernerite, and Fig. 60 is a map of the top of the same crystal, or a basal section, as it is called. Note the prism and pyramid of the unit series, *m* and *r*; the prism and pyramid of the diametral series, *a*, *e*; also the eight-sided prism *h* and the double eight-sided pyramid *z* already referred to.

All of the forms that have been described belong to what is called the TETRAGONAL SYSTEM, in which the planes are referred to three axes at right angles, of which the two in the horizontal plane are equal, the third or vertical axis is longer or shorter.

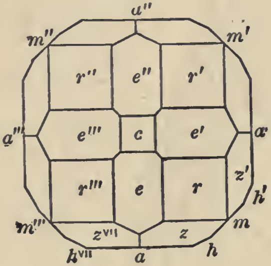
It will be seen by examining the figures, especially Figs. 58, 59, 60, that the grouping of faces is the same about the faces lettered *a*, but different from them about the face *c*, the basal plane. It will be seen, too, that about *c* the faces of the same kind are all arranged in fours or eights.

In other words, all these tetragonal crystals have a pair of equal planes of symmetry parallel to the faces *a* and at right angles to each other. There is also another pair at right angles to each other parallel to the faces *m*. All these four planes meet in a common vertical line, which is called the vertical axis.

59.



60.

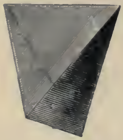


There is, finally, a fifth plane of symmetry parallel to the top and bottom of the crystal, or the basal plane *c*, and hence at right angles to this vertical axis, but it differs from either of the other pairs.

In the Tetragonal System there are also some half-forms but only one will be specially described.

Sphenoid.—The sphenoid (Fig. 61) is a four-faced solid looking like a tetrahedron, but differing from it since the faces are isosceles (not equilateral) triangles. It is described as the half-form of the square pyramid shown in Figs. 41 and 51.

61.



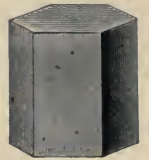
III. *Hexagonal System.*

The chief forms of the Hexagonal System are the two six-sided prisms, the two double six-sided pyramids, and the twelve-sided prism and double twelve-sided pyramid.

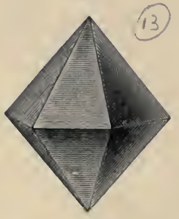
These will be briefly described first, and then the characteristic forms of the Rhombohedral part of the Hexagonal System will be mentioned.

Hexagonal Prism and Pyramid.—The hexagonal prism and pyramid are shown in Figs. 62 and 63, while Fig. 64 gives a combination of the two. The angles of the hexagonal prism are exactly 120°, and the terminal face or basal plane is a regular hexagon. The faces of the hexagonal pyramid are isosceles triangles, differing in angle according to whether the pyramid is more obtuse or acute.

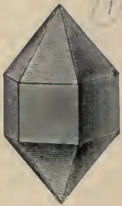
62. 13



63. 13



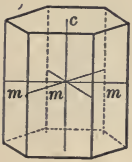
64. 1



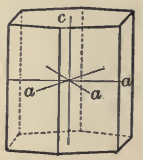
These angles, and the others that depend upon them, are characteristic for a given species.

There is also another hexagonal prism and pyramid diagonal to the others and looking much like them. These two sets correspond to the two square prisms and pyramids of the Tetragonal System. Compare Fig. 65 of the unit prism and Fig. 66 of the second or diagonal prism and note the position of the axes shown in each; also the position of the axes in Fig. 67 of the unit hexagonal pyramid. Fig. 68 shows the combination of the unit hexagonal prism and pyramid with the basal plane. Fig. 69, of a crystal of beryl, shows a combination of the unit prism and pyramid, *m* and *p*; the diagonal prism and pyramid, *a* and *s*; also the basal plane *c*.

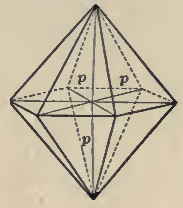
65.



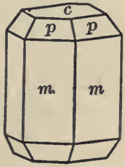
66.



67.

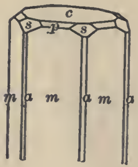


68.

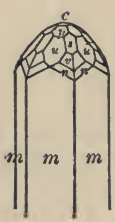


There is also a prism bounded by twelve similar faces, and a double pyramid bounded above and below by twelve triangular faces. This double twelve-sided pyramid is often called a *berylloid,* because common with crystals of beryl. Two berylloids are shown in Figs. 70, 71; the faces are lettered (in part) *n* and *v* respectively. Fig. 71 is an enlarged map, or basal section, of the top of a crystal much like that of Fig. 70. Note, also, on Fig. 71 the hexagonal prism, *m*, and pyramids, *u* and *p*, of the unit series; the prism, *a*, and pyramid, *s*, of the diagonal series.

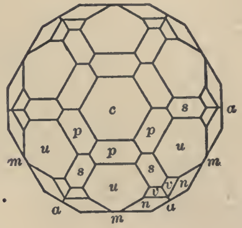
69.



70.



71.



These hexagonal forms belong to the HEXAGONAL SYSTEM, where the planes are referred to the four axes shown in Figs. 65, 66, 67, three in a horizontal plane equal and cutting each other at angles of 60°, and the fourth vertical axis either longer or shorter.

It will be seen that the faces are arranged in the same way about each face *a* and hence about each end of the horizontal or lateral axes, but differently about the basal face *c*, that is, at the extremity of the vertical axes. The faces are arranged about the face *c* in sixes or in twelves instead of fours and eights as in the Tetragonal System.

All the hexagonal forms have three equal planes of symmetry making angles of 60° with each other parallel to the faces *m*; also another set of three, diagonal to the others and parallel to the faces *a*; and a seventh plane parallel to the top or base of the crystal.

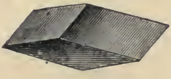
There are several half-forms in the Hexagonal System, but the only ones that will be described here are those of the Rhombohedral System.

Hemihedral Forms (Notes f

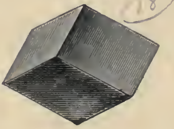
The Rhombohedral System is generally treated as a branch of the Hexagonal System. In the forms belonging to it the faces are in threes about the extremities of the vertical axis *c*, and there are only three vertical planes of symmetry making angles of 60° with each other intersecting in this axis. The important forms are the rhombohedron and the scalenohedron.

Rhombohedron.—The rhombohedron is a six-sided solid, each face of which is a rhomb; it is shown in Figs, 72, 73, 74. There may be a great many rhombohedrons, as shown

72.

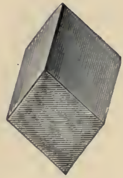


73.



(8)

74.

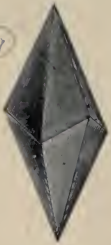


here, differing in angle and consequently more or less obtuse or acute. The rhombohedron looks somewhat like a cube if the cube is placed with the line joining two opposite angles vertical; in fact, the cube comes between the obtuse and acute rhombohedrons, having an angle of just 90°.

The rhombohedron may be regarded as a half-form of the hexagonal pyramid, but this subject is a rather difficult one and cannot be followed up here.

Scalenohedron.—The scalenohedron (Fig. 75) is a twelve-sided solid, looking a little like a double six-sided pyramid, but the faces are scalene triangles and the edge is zigzag, up and down, like that of a rhombohedron, instead of horizontal as in the pyramid. Moreover the angles between the faces over the edges which meet in the vertex are only alike every other one—in other words, there are two sets of three each, those of one set more obtuse than those of the other.

75.

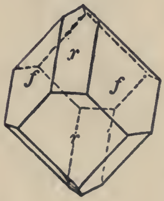


e Notes p31 (11)

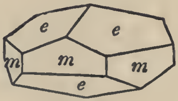
The two hexagonal prisms before described and the hexagonal pyramid of the diagonal series also belong to the Rhombohedral System.

The number of species crystallizing in the rhombohedral division of the Hexagonal System is very large, and some of them, as, for example, calcite, are very highly complex. In the figures of calcite given here, 76 to 80, the faces r, f, e belong to different rhombohedrons; v to a scalenohedron; m is the unit hexagonal prism; c the basal plane.

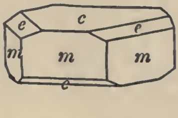
76.



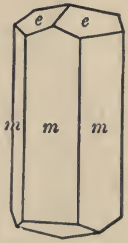
77.



78.



79.



80.

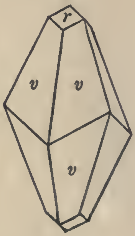
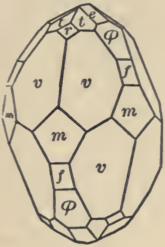
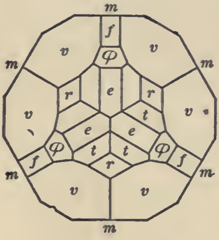


Fig. 81 represents a more complex crystal, also of calcite, and Fig. 82 gives a basal projection of it. Here there are several rhombohedrons, r, e, ϕ, f; the scalenohedrons *v* and *t*; the prism *m*. These figures show well the symmetry about three planes meeting in angles of 60°. Fig. 83 shows a crystal of hematite; *u* and *r* are faces of two rhombohedrons, and *n* faces of the hexagonal pyramid of the diagonal series.

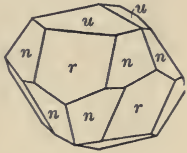
81.



82.



83.

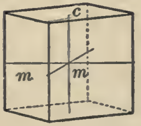


IV. *Orthorhombic System.*

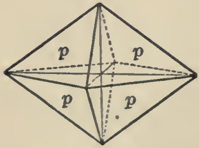
The characteristic forms of the Orthorhombic System are the rhombic prism and pyramid; there are also other forms called domes.

Rhombic Prism.—Fig. 84 shows what is called a rhombic prism, the terminal face of which (formed by the basal plane *c*) is a rhomb, not a square as in the square prism, which it somewhat resembles. The angle between two faces over one vertical edge is obtuse, or greater than 90°,

84.



85.

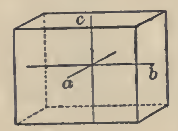


the other acute and just as much less than 90°. For instance, if the angle of the front edge is 100°, the angle of the side edge would be 80°. There may be a great many rhombic prisms on the crystals of the same species, differing in the angles of their two edges.

Rhombic Pyramid.—The rhombic pyramid is shown in Fig. 85; its cross-section, like that of the prism, is a rhomb, and its edges belong in three sets, with different angles for each. These angles are characteristic for the crystals of a given species. There may be a great variety of rhombic pyramids, differing in their angles, and each corresponding to a given rhombic prism.

Fig. 86 shows a combination form belonging to this system which looks like a cube a little, and resembles it in that the angles between the faces are 90°, but differs because the faces instead of being all alike belong in three sets of two each. It is for this reason that they are lettered *a*, *b*, *c*. Of these *c* is called the base, and *a* and *b* are called pinacoids. This form also resembles the second or diametral prism of the tetragonal system (Figs. 45 and 50); but in that form the four vertical faces (*a*) were all alike, while here, as has been stated, they are only alike two and two.

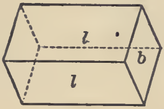
86.



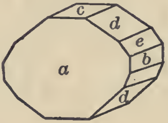
Domes.—The forms shown in Figs. 87, 88 are called domes, from the Latin for house (*domus*), because when they meet above they make a horizontal edge like a hip-roof. These domes are often and very conveniently called horizontal prisms; that of Fig. 87 is also called a *macrodome,* because the faces (*l*) are parallel to the longer lateral axis (see Fig. 84); those (*e*, *d*) of Fig. 88 are similarly called brachydomes, because the faces are parallel to the shorter axis.

Figs. 159–161, of sulphur, on p. 171, show some simple orthorhombic crystals; the faces *p* and *s* belong to rhombic pyramids, and *n* is a dome. Fig. 89 shows a more complex crystal, and Fig. 90 is a basal section of the same. Here the faces lettered *e*, *f* belong to two rhombic pyramids; *d*, *h*, *k* to domes; *a*, *b* are pinacoids, and *c* is the base.

87.

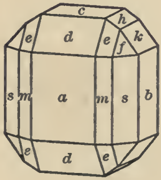


88.

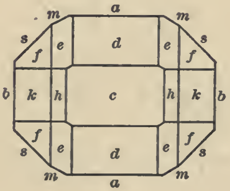


All these rhombic forms belong in the ORTHORHOMBIC SYSTEM, in which the planes are referred to three unequal axes at right angles to each other, as shown in Figs. 84, 85, 86.

89.



90.

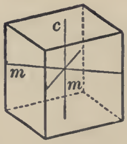


It will be seen that the grouping of faces about the extremities of each of the axes differs from that about the others, but there are three planes of symmetry parallel to the faces *a, b, c*, which, however, are all unlike.

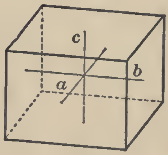
V. *Monoclinic System.*

Oblique Rhombic Prism.—Fig. 91 shows an oblique rhombic prism in which the end plane is rhombic in form, but it is oblique to the faces of the prism, instead of being at right angles as described in the Orthorhombic System. This oblique prism and a variety of other forms of the same group belong to the Monoclinic System, in which the planes are referred to three unequal axes, two of the angles between which are right angles, while the third (in front) is obtuse. In Figs. 91 and 92 the forms resemble Figs. 84 and 86 somewhat, but the top or basal plane *c* is inclined to the front edge of *m* (Fig. 91), and to the plane *a* (Fig. 92), not at right angles to them; the faces *a, b* are also called pinacoids, while *m* is the prism.

91.

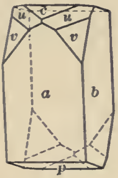


92.

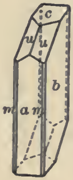


The monoclinic forms are too difficult to be described fully here, but it is not hard to learn what is most essential about them. Thus in Figs. 93 to 95 (of pyroxene) it is seen that the faces are in pairs alike on either side of a middle plane parallel to the face lettered *b*. In other words, this middle plane parallel to *b* is a single plane of symmetry, the only one existing. The forms are named much as in the Orthorhombic System: *m* is a prism; *u, v, o* are pyramids (half-pyramids since each face occurs only four times); *a, b* are pinacoids, and *c* is the basal plane.

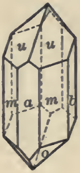
93.



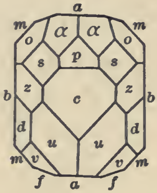
94.



95.



96.



Planes on the alternately obtuse and acute edges between *c* and *a* (Fig. 92) are called *orthodomes;* those on the four similar edges between *c* and *b* are *clinodomes.*

97.

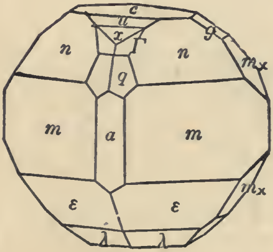


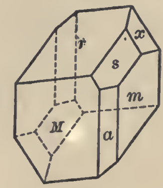
Fig. 96 shows a basal projection of a more complex monoclinic crystal; here the symmetry parallel to the faces *b* is clearly exhibited. Fig. 97, of datolite, shows another complex monoclinic crystal; here g, m_x, are clinodomes, also u, x, orthodomes; n, ϵ, λ, Γ, q are all pyramids.

VI. *Triclinic System.*

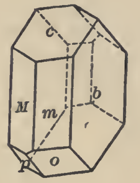
Finally there is one other group of forms, which belong to the Triclinic System. In this system the planes are referred to three unequal axes all oblique to each other. Here all the intersections are oblique and the like faces are in pairs only on opposite sides of a crystal; there is no plane of symmetry at all.

Fig. 98, of axinite, and Fig. 99, of albite feldspar, show two triclinic crystals. Here it is seen that the like planes are in sets of two each, one in front, the other behind, represented in dotted lines. In Fig. 99 there is some resemblance to a monoclinic crystal, but the angle between the faces *b* and *c* is not 90° as it must be there; and moreover the angles *bm*, *bM* are different, as are also the angles *bo*, *bp*. Hence *m* and *M* are different planes, and also *o* and *p*.

98.



99.



The subject of triclinic crystals will not be carried further, because of its great difficulty.

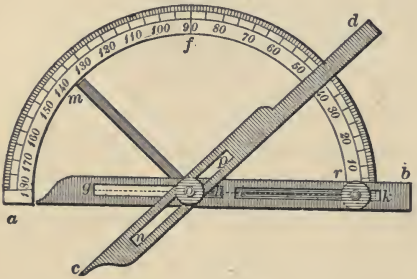
When we come to examine a large number of crystals of different species, we are at first discouraged by the almost infinite variety which we find. But as we gain in experience, much of this difficulty gradually disappears and we become able to classify a large part of them into one of the six groups or systems which have been mentioned. To learn all about crystals, however, is a difficult matter, and it will be best for the student to master the other characters of minerals, and to become well acquainted with the common species, before taking up a larger book to study the subject of crystallography in detail.

MEASUREMENT OF ANGLES.

It is a help in studying minerals to be able to measure the angles between the faces of a crystal, for in this way it is possible to tell a square prism from a rhombic prism, a cube from a rhombohedron, and so on. The simplest method, when the crystal is large enough, is to use the instrument shown in Fig. 100, called a *contact goniometer.*

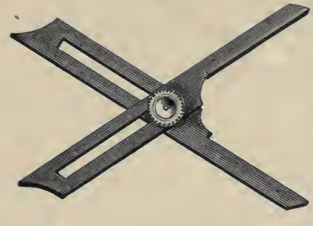
This is best made of brass with a circle or semi-circle, divided accurately into degrees and half-degrees, and provided with two arms moving on a pivot at the center. In Fig. 100 these arms are fixed at the center *o*, and supported by *om*, but they can slide forward and back so as to accommodate them to crystals of different size. The crystal is placed between the jaws *a* and *c*, in such a position that the two faces whose angle is to be measured are *exactly in contact* with them, and the edge between these faces is *at right angles* to them. The angle (measured from the zero, 0°, at *k*) is then read off from the upper edge of *d*, for the lines from *d* and *k* pass precisely through the center *o* and are parallel to the edges at *a* and *c*.

100.



A very fair substitute for an expensive goniometer can be made from a cheap protractor, by first cutting out two arms of thin wood shaped like the steel ones of Fig. 101, and then putting through a brass pivot on which they can turn.* It is not necessary nor desirable that these arms should be permanently attached to the protractor. One pair of edges (the inner edges to the right in the figure) must be exactly in line with the center or pivot; between them the angle is read off when the arms are placed on the protractor, the pin then passing through its center and one edge through its zero. The other pair of edges (to the left) must be parallel to those first mentioned, so as to give the same angle; the two faces of the crystal whose angle is to be measured are placed between them, as before explained.

101.



For measuring the angles between the faces of very small crystals an instrument called a *reflecting goniometer* is used. This is described in larger works. It is somewhat expensive, and its use requires both skill and experience. It demands, moreover, polished faces if good results are to be obtained.

IRREGULARITIES OF CRYSTALS.

Distorted Crystals.—Most of the crystals of minerals would give a very poor impression of nature's workmanship to one who expected always to see them exactly like carefully-made models, or like the figures given on the preceding pages. The cubes of galena which we find are often flattened or drawn out. An octahedron (Fig. 102) may be flattened so as to look like Fig. 103; a dodecahedron (Fig. 104) may take the forms shown in Fig. 105 or 106. And so of other crystals. But it is not really to be supposed that the forms are badly made, like a bad model; on the contrary, the size of the like faces on a crystal may vary, and so the shape of the solid as a whole, but *the angles* between them remain the same. Moreover, when we study a crystal more carefully, we find that what is really essential is not the size or shape of each face, but the way in which the little molecules of which the whole is built up are arranged. For example, in a cube the essential point is the fact that the structure is the same in the direction of the three cubic faces. It follows from this that in the cube not only are the angles between two adjacent faces

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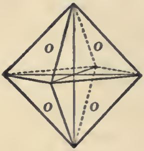
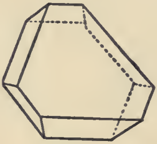
* One of the small brass screws used to fasten together sheets of manuscript can be employed.

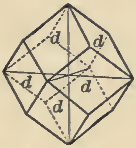
102.



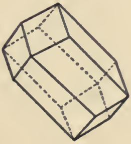
103.



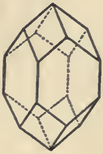
104.



105.



106.

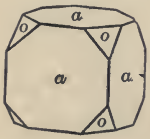


always 90°, but the six cubic faces are all similar; and therefore if there is the easy fracture, called cleavage, parallel to one cubic face, there will be the same cleavage also parallel to the others. But the actual size of the faces is a matter of no importance. In fact, in one species the cubes are sometimes lengthened so as to be like fine hairs.

Similar remarks can be made in regard to the distorted octahedron and dodecahedron figured above, and indeed about any distorted form. The symmetry in the molecular structure, and hence the angles between the faces, remain unchanged, although the symmetry of the external geometrical form is not that of the ideal crystal.

Another good example of what is possible in a distorted crystal can be explained by referring to Fig. 107, a cube with octahedral faces on its solid angles. Now instead of this, the ideal form, it is common to find in natural crystals no two of the triangular octahedral faces of the same size; some of them may even be absent; while the cubic faces vary widely also. But such a crystal is not essentially different from Fig. 107, for every octahedral face is identical with each of the others if it is equally inclined to the three adjacent cubic faces, that is, to the three crystallographic axes, even if the faces all differ in size. In other words, it is here, as always, the position of the face, as showing the kind of molecular structure, not its size, which is essential.

107.

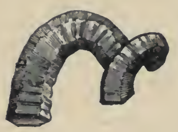


In the same way a cube may in nature look like a square prism, for the angles between the faces are all right angles in both cases, and so the goniometer will not tell the difference between them, as has been already explained; but the molecular structure of the two is not to be confounded. In the square prism there is the same arrangement in the transverse directions, but a different one up and down; hence the square top of the crystal is not like the four similar oblong vertical faces, and we may find cleavage parallel to one set and not to the other.

From the fact that so much variation is possible in the size of the like faces on a crystal, and hence in the shape of the whole, it is evident that the practical study of natural crystals is much more difficult than the study of the models which give the ideal forms. This is especially true because most crystals are so implanted on the rock, or embedded in it, that only part of the form has been developed. Thus quartz crystals are often attached at one extremity, while only the other end has had a chance to grow freely. Or the crystals may be implanted upon a surface of rock so that only a series of minute faces and angles are visible. In such cases the study of the form is really a difficult matter requiring much skill and experience, and the beginner should not be discouraged because he cannot tell at once what the form of a crystal really is. Even here, however, some conclusion can often be drawn from the shape of the faces: thus, if regular triangles, they probably belong to an octahedron; or if rhombs, to a rhombic dodecahedron; and so on.

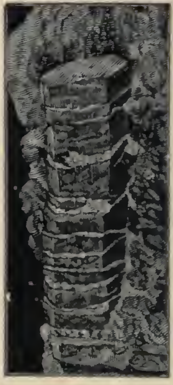
Besides the crystals that have been just spoken of, which, while they look at first irregular, are really perfect in the matter of the position of the faces and of the angles between them, there are others which are really deformed.

108.



Some peculiar conditions attending the growth of the crystal, or perhaps some force which has acted upon it since it was formed, has resulted in bending or twisting it out of its normal shape, so that it may differ widely in angle from the regular form. Thus the faces may be curved, as with the barrel-shaped crystals of pyromorphite, or like the peculiar convex faces common on crystals of the diamond; or the whole crystal may be bent, as is seen sometimes in the case of crystals of quartz, or of stibnite, or of some kinds of chlorite (Fig. 108).

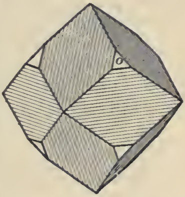
109.



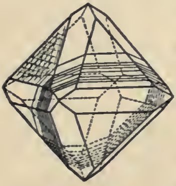
Or again, aside from this curving and twisting, a crystal may have had its shape more or less changed by some force exerted in the rock since it was made; it may even have been broken and again cemented together, so that many irregularities may result. Fig. 109 shows a crystal of beryl which has been broken into many pieces, these slightly displaced from each other, and the whole cemented together by quartz.

Other irregularities of crystals besides that mentioned also occur. The faces of crystals, instead of being perfectly smooth, are often rough, perhaps because made up of a multitude of crystal points. Or they may be covered with fine lines, or *striations*, as those on the cubic faces of pyrite (see Fig. 183 on p. 213), which are explained by the successive combination of another face (the pyritohedron) in narrow lines with the cubic face. In Fig. 110 the fine lines represent striations on a dodecahedral face due to the presence also of the octahedron. This *oscillatory combination,* as it is called, may go so far as to make the crystal nearly round, like some prismatic crystals of tourmaline. Striations are also sometimes due to twinning, as is common with the triclinic feldspars (see p. 59, also Fig. 272, p. 289). Fig. 111 shows an octahedral crystal of magnetite with twinning lamellæ appearing as striations on an octahedral face.

110.



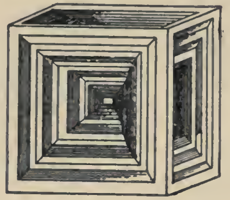
111.



Again, the faces may have a multitude of little elevations or depressions, the latter like the pits spoken of on p. 65 as produced by etching; in fact their presence can sometimes be explained as due to etching by nature. The same cause—the action of some partial solvent after the formation of the crystal—often explains the rough faces alluded to. Connected with the subject of minute elevations on the face of a crystal is the replacing of the face by one or more others varying a very little from it in angular position. The very low pyramids seen on some cubes of English fluorite are good examples of this (see Fig. 211, p. 245). Such planes are often called *vicinal* planes (from the Latin *vicinus,* neighboring).

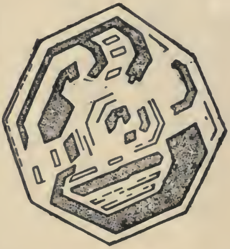
Crystals which have formed rapidly may have only a more or less regular skeleton shape, like the crystal of salt represented in Fig. 112. The salt-crystals sometimes show distinctly one face only with the depression in the center, so that they are called hopper-shaped crystals. The cavernous crystals of pyromorphite and vanadinite give other examples. Crystals, often for the same reason, enclose foreign substances, sometimes in the form of liquids, as the quartz crystals that contain water, occasionally with a movable bubble of air. Or the liquid may be carbon dioxide, then often with a bubble of the same substance in the form of gas. In such cases the crystal must have been formed under great pressure, sufficient to keep the gas in the liquid form. Fragments of such crystals heated in the gas-flame fly to pieces with great violence, because of the expansion of the gas formed from the liquid by heat.

112.



Crystals, too, frequently contain foreign solid substances of many kinds; quartz crystals thus enclose clay, particles of carbon, etc. The famous groups of large calcite crystals from Fontainebleau contain some sixty per cent of sand; it is most remarkable that the force of crystallization was powerful enough to marshal into place the calcite molecules under such circumstances. Sometimes the impurities are regularly arranged in the crystal, and then a curious effect is obtained in a cross-section cut and polished. Fig. 113, of garnet enclosing quartz, shows this well

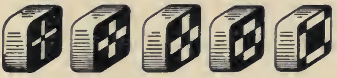
113.



Another interesting example is afforded by the variety of andalusite called macle or chiastolite. Sections obtained at different points in a long crystal, when polished, may show the forms given in Fig. 114.

Pseudomorphs.—A peculiar class of false forms, in which the crystalline shape does not belong to the chemical substance, must be briefly described here. These are called *pseudomorphs.*

114.



Pseudomorph* means *false form*, and the name is applied to a specimen having the form characteristic of one species and the chemical composition of another. This seemingly difficult contradiction is easily explained. Most chemical compounds are liable to undergo a change or alteration when subjected to certain conditions, as moisture, the action of alkaline waters or acid vapors. Thus oxide of copper, the mineral cuprite (Cu_2O), is rather easily changed chemically to the carbonate of copper, called malachite ($CuCO_3.Cu(OH)_2$); the calcium sulphate, anhydrite ($CaSO_4$), assumes water and changes to the hydrated sulphate, gypsum ($CaSO_4 + 2H_2O$); the sulphide of iron, pyrite (FeS_2), changes to the hydrated sesquioxide, limonite ($2Fe_2O_3.3H_2O$).

Now, in these and similar cases, if the original mineral was in crystals the external form is usually preserved, often perfectly, while the chemical nature and the molecular structure have changed. Hence we describe the false forms mentioned as pseudomorphs of malachite after cuprite, so too gypsum after anhydrite, limonite after pyrite.

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* From ψευδής, *false*, and μορφή, *form.*

Other examples are pseudomorphs of chlorite after garnet, pyromorphite after galena, kaolin after feldspar. In a few rare cases, where the same chemical compound occurs in nature in two distinct crystalline forms, each with its own molecular structure, a change may take place in the structure of one of these minerals without alteration of the chemical substance. Thus the rare mineral brookite (titanium dioxide, TiO_2) may be changed to rutile (also TiO_2). Such pseudomorphs have the special name of *paramorphs.*

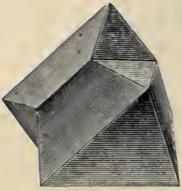
The cases where the original substance has entirely disappeared and some other has come in to take its place are also called pseudomorphs. Thus we occasionally find quartz in the form of calcite, or of fluorite, or of barite, that is, pseudomorph after one of these; also tin-stone in the form of orthoclase feldspar; native copper in the form of aragonite. Even fossil wood may be said to be a pseudomorph of quartz or opal after the original wood, the structure of which it sometimes preserves with wonderful perfection.

GROUPINGS OR AGGREGATIONS OF CRYSTALS.

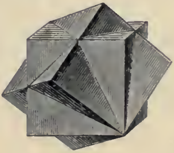
Some crystals occur isolated and alone, and then the form is usually developed on all sides, and with something of the regularity which the ideal model shows. Thus we find perfect garnets in mica schist or granite, and gypsum crystals in clay. But it is still more common to find crystals grouped together either irregularly, as in the majority of cases, or perhaps in parallel position, or again in the peculiar way called twinning; the last mentioned will be described first.

Twin Crystals.—The most interesting and important case of the grouping of crystals, or parts of crystals, is shown in those curious complex forms called TWINS. Fig. 115 represents a twinned octahedron, and Fig. 116 two twinned cubes. In the first case the growth of the crystal as a whole has been such that one half has been developed in reversed position to the other, as if it had been revolved around through half the circumference or 180°, and this about an axis (called the *twinning axis*) at right angles to two opposite octahedral faces.* This is described as a *contact-twin*.

115.



116.



In Fig. 116 the two cubes interpenetrate each other, but each one is in such a position as if it too had been revolved 180° around an axis running through two diagonal angles (the same octahedral axis as in the first case). This is called a *penetration-twin*.

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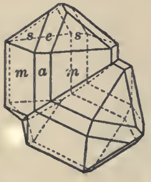
[*] Such a line joining the middle points of two opposite octahedral faces is called an *octahedral axis*.

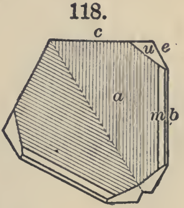
These two cases illustrate all that is most essential about a twin. In every case the two crystals, or parts of crystals, are in such a position that one seems to have been turned around 180° with reference to the other, and this usually about an axis at right angles to some simple crystalline plane, which is then called the *twinning-plane.*

Fig. 117 shows a twin crystal, of the contact type, of cassiterite or tin-stone; Fig. 118 one of columbite, which also illustrates the point that the difference in direction of the striations of the two halves shows that the crystal is twinned. Fig. 119 again is a penetration-twin of staurolite, also called cross-stone. Figs. 120, 121, 122 show what are called repeated twins. These last are often very regular in form, the complex or twinned crystal being made up of perhaps three, five, six, or even eight parts of crystals or complete crystals, symmetrically arranged so as

117.



118.



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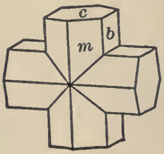
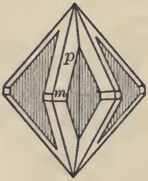


120.



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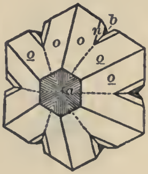

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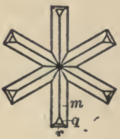
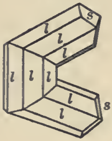


to resemble a star in many cases. Fig. 123, of rutile, shows another kind of repeated twinning.

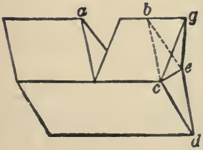
123.



Still again the twinning may be repeated in the form of thin parallel layers, each in reversed position to the next. This is called *polysynthetic* twinning and is best illustrated by a piece of a triclinic feldspar showing fine lines or striations on a surface of basal cleavage; these lines are simply the edges of the thin successive parallel plates. By holding the specimen so as to catch the reflection of light from a distant window and turning it through a very small angle it may be seen that first one set of edges reflect together and then the other. This is illustrated by a figure of albite on p. 289. Fig. 111 on p. 53 shows polysynthetic twinning lamellæ in a crystal of magnetite.

It will be understood that the revolution spoken of has not actually taken place in ordinary cases; the rule is simply given in this form so as to show best the mathematical relations in position of the two parts. Still it is most interesting to note that in a few cases it is possible to cause the molecules of part of a crystal to change their position so as to produce twinning artificially, as by pressure in the proper direction.

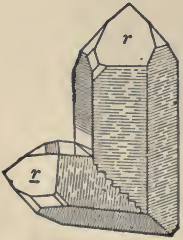
124.



Thus Fig. 124 represents a cleavage piece of calcite placed with its obtuse edge on a firm surface and then pressed by a knife (not too sharp) at *a*. Steady uniform pressure serves to reverse the position of the molecules in the part lying to the right so that the whole is pushed to the side and assumes a twinned position with reference to the rest. If skillfully done, no change in the transparency of this part takes place and the new surface *gce* is perfectly smooth. In nature pressure may have produced twinning after the formation of the crystal; it is then called *secondary twinning*. The twinning layers or lamellæ observed in most cleavage masses of otherwise clear calcite are often to be explained in this way. This may also be true in some cases of the similar layers common on large crystals of pyroxene and which cause a separation or "parting" parallel to the basal plane, appearing much like the easy fracture called cleavage.

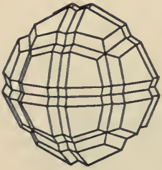
It is evident that, since the crystals on a single specimen of a species may be grouped in a great variety of ways, it is not always easy to decide whether a given case is a twin or not; this often becomes a matter requiring careful study, exact measurement of angles, and calculation, perhaps also of optical study. For example, it is common to find quartz crystals crossing each other at a great variety of angles, but real twins like Fig. 125 are rare. The two parts of a true twin are usually symmetrical with reference to the twinning plane, and there is always the reversal of one half in the way described.

125.



Parallel Grouping.—One very common case of the grouping of crystals, which the beginner is apt to confound with twinning, is where the crystals or parts of crystals are parallel to each other, so that the axes of all have the same directions, and are not inclined as in most twins. This is illustrated by a pile of cubes with faces parallel and having re-entrant angles between them. The crystals of many species are at times arranged in this way, but in every case it will be found that if the complex group is held so as to reflect the light from a window, the faces in adjoining crystals which reflect at the same time are always similar faces. An octahedron of fluorite, built up of a multitude of little cubes in parallel position, is a not very rare example of this. Fig. 126 shows a complex crystal of analcite, formed of a number of single crystals all parallel; it is hence *not* a twin. The large and complex crystal of quartz which forms the frontispiece illustrates well this parallel grouping in the subordinate parts.

126.



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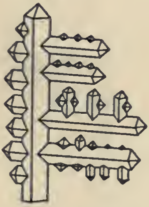
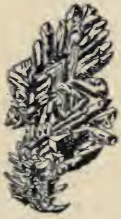
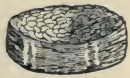


128.



Parallel grouping is most interesting when the result is to build up a compound form with branching and rebranching parts like the limbs of a shrub or tree, and hence giving rise to a kind of structure called *arborescent* or *dendritic;* here all the crystals or parts of crystals have their axes in the same direction. This is shown in Fig. 127, of native copper. Fig. 128 is similar, though here there is also some twinning, but not distinctly shown on so small a scale.

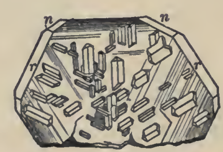
129.



In Fig. 129 the little plates of hematite are grouped together so as to form a large crystal, but with such variation in their position that the top has the shape of a rosette. Such a crystal is called by the Germans an *Eisenrose,* or iron-rose.

Another curious and interesting case is where a number of crystals are implanted upon the surface of another which has obviously so influenced their growth that they are in parallel groups, and in a definite position relative to it. Many cases of this have been noted, as, for example, the rutile crystals on a tabular crystal of hematite, as shown in Fig. 130. Fig. 131 is a related case; it consists now of rutile alone, and has been described as a pseudomorph (see p. 55) of rutile after hematite. In the natural healing of the broken surface of a crystal, as of quartz (alluded to on p. 20), it follows, almost as a matter of course, that the new molecular growths should be in directions parallel with the old ones.

130.



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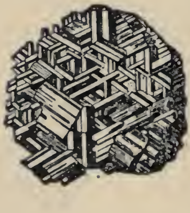


The common method of grouping of crystals, however, is quite irregular, and it is only exceptionally that twins or parallel groupings are noted. And here a few terms often used in describing specimens must be explained;

they are given to describe the way the crystals or crystalline parts are aggregated.

If the crystals are very small and closely clustered, giving a rough surface a little like coarse sandpaper, it is said to be *drusy.* Or the crystals may cross each other more or less regularly like the meshes of a net, and this form is said to be *reticulated.* When the crystals or crystalline fibers making up a mass are very slender, something like needles, the structure is said to be *acicular;* if they are fine like hairs, and perhaps found in a tangled wad, it is said to be *capillary;* if fine and soft like moss, *mossy.*

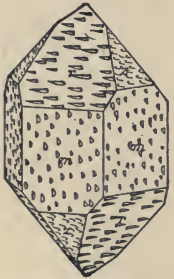
Structure in General.

Minerals are not always in distinct crystals, like those of garnet or quartz, or even in aggregates of crystals. On the contrary, many of the specimens in a mineral cabinet show no crystalline faces at all, and then they are simply called *massive.* There are, however, important distinctions of structure between massive minerals.

First of all, the distinction between *crystalline* and *amorphous* must be well understood. A piece of clear quartz, or rock crystal as it is often called, is said to be *crystalline;* a piece of glass which very likely the eye alone could not distinguish from it is *amorphous* or *formless.* For the mass of quartz, though it has no definite external form, but is bounded only by irregular fracture surfaces, is just as truly crystalline in structure as a perfect crystal; in fact it may be itself a fragment of a large crystal. This is true because the essential idea about a crystallized mineral is that there should be the regular arrangement of the molecules out of which it is built up. It is not always easy, often impossible, with the eye alone to decide whether this regularity of structure exists. It is shown by the cleavage, as will be explained in a later part of this chapter; but when there is no cleavage, it is usually by optical examination in what is called polarized light that this can be most easily proved. For example, the bright colors given by a thin fragment of a quartz crystal in polarized light shows at once, to one who understands the subject of optics, that it is crystalline in structure.

In the glass, on the other hand, the molecules have no definite arrangement at all, and hence no action on polarized light. It is somewhat like the difference between a pyramid built of blocks of stone laid in regular rows or after a more intricate pattern, and one in which the blocks are tumbled in without order—only here we should need mortar to cement the whole together, while nature's molecules, in either case, are bound together by the force of cohesion.

132.



It is interesting to note here one of the ways which the skillful mineralogist has of finding out how the molecules of a crystal or crystalline mass are arranged: and this may be a very important matter, for next to the chemical substance this molecular structure is the most essential character of a mineral. He does this by what he calls etching, that is, by allowing some liquid (or sometimes a gas), which has the power of dissolving the substance examined, to act upon a smooth surface for a short time. Then it is removed, the surface washed off and examined under the microscope. Often a multitude of little cavities or pits are found on the surface whose shape shows clearly how the molecules are built up. It is very much as if the stones of the pyramid spoken of were so smooth and closely fitted that no joints were visible, and the mason should go to work and pull out a number till he could see what the pattern was. Fig. 132 shows the etching-figures on the faces of a crystal of quartz; the variation in their form reveals the complex structure which is described further on p. 275.

To continue the discussion of the structure of massive minerals.—In general it can be said that such specimens are crystalline in structure even when there is no distinct evidence of it to the eye, for the amorphous glasslike condition is the exception, not the rule. There are, however, cases in which the structure seems to be intermediate between the distinct crystalline and the amorphous, and this is called *crypto-crystalline,* as is true of many of the massive kinds of quartz. Among the specimens of massive crystalline minerals there are a great variety of different kinds of structure, and it is necessary to become acquainted with the terms used in describing these.

It has been stated that the easy fracture in certain directions, called *cleavage,* is the surest and easiest way of showing that a massive mineral is crystalline in structure. Such a mass is said to be *cleavable,* which means capable of being cleaved, or showing cleavage. The kinds of cleavage are spoken of more fully on pp. 70–72. This cleavage proves that the mass is crystallized, and also often reveals what sort of structure it has. The cleavage may be in the same direction in all parts of the mass, as if it were a piece of one large crystal; or, more commonly, the cleavage directions may be the same in one little spot only—that is, for each individual grain. In the second case the mass is obviously crystalline and the structure is said to be *cleavable* and *granular*. Such a mass of galena is really made up of a multitude of little grains, each one of which has its own directions of cleavage and presents to the eye its own edges. If the individual grains are large, the structure is said to be *coarse-granular;* and if small, it is *fine-granular*. From the latter we pass to the closely *compact* kinds in which the structure is sometimes not obvious to the eye at all; they may then be said to be *impalpable*. But this extreme is rare; for example, a piece of white marble, even if it is so fine-grained that the particles cannot be seen by the eye, usually sparkles in a strong light from the reflection of the multitude of minute cleavage-faces.

This granular structure may belong also to other minerals which do not have the distinct evidence of crystalline structure in the cleavage, and then the grains may often be more or less easily separated from one another; sometimes, as in granular kinds of pyroxene, they are found to be imperfect crystals.

Again, if the mass seems to be made up of layers, whether separable or not, it is called *lamellar*. If it is in thin leaves or plates, which can be separated from one another, it is called *foliated,* as with graphite. It is further called *micaceous* when the separation takes place as readily as in a piece of mica.

If the mass is made up of little columns, it is called *columnar.* When there are distinct fibers, it is said to be *fibrous;* asbestus is said to be fine-fibrous, and with it the fibers are easy to pull apart, or *separable,* but this is not always the case. There are many intermediate kinds between the fine-fibrous and coarse-columnar.

If the fibers, or little columns, or leaves all go out from a center like the spokes of a wheel, the structure is said to be *radiated,* as wavellite (Fig. 133), or perhaps *stellate* when it is star-shaped, as gypsum (Fig. 134). If the layers are arranged in parallel position about one or more centers, the structure is said to be *concentric,* as malachite (Fig. 135). All these terms, granular, foliated, lamellar, columnar, fibrous, radiated, etc., ordinarily refer to the structure of the mass when it is more or less distinctly crystalline.

When the external surface of the mineral is in the form of rather large rounded prominences, it is called *mammillary,* as malachite (Fig. 136); if the prominences are smaller, somewhat resembling a bunch of grapes, it is called *botryoidal,* as prehnite, smithsonite, and chalcedony (Fig. 137). If the surface is made up of little spheres or globules, it is called *globular,* as hyalite or prehnite (Fig. 138). If the form is that of a kidney, it is called *reniform,* as hematite (Fig. 139). It will be understood that there is no sharp line dividing these different cases.

Sometimes the mineral takes the form of a delicate

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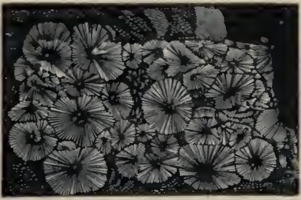

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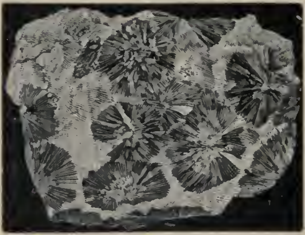

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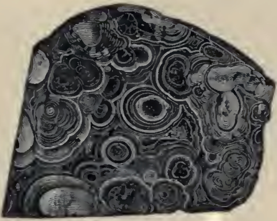

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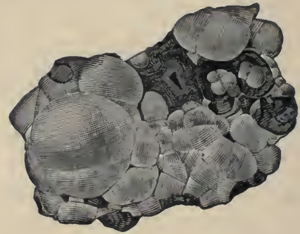

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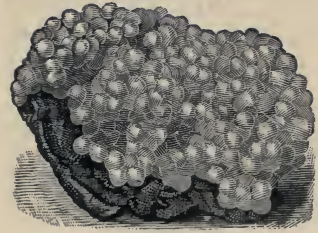

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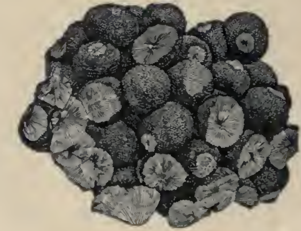

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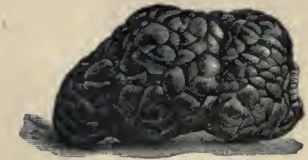

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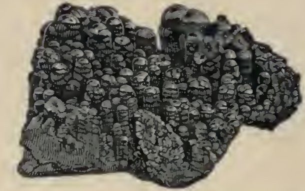
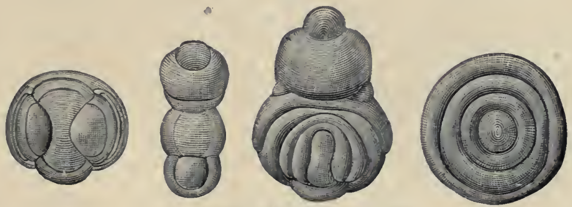


Figs. 133 to 140, varieties of structure: 133, Wavellite, *radiated;* 134, Gypsum, *stellate;* 135, Malachite. *concentric;* 136, Malachite, *mammillary;* 137, Chalcedony, *botryoidal;* 138, Prehnite, *globular;* 139, Hematite, *reniform;* 140, Limonite, *stalactitic.*

branching coral, and it is then called *coralloidal,* as certain varieties of aragonite (which see). If made up of forms like small stalactites, it is said to be *stalactitic,* as limonite (Fig. 140).

141.



Concretions from Clay-beds.

If the material has clustered about a center like those curious forms of impure calcium carbonate—called concretions — common in the clay (Fig. 141), it is named *concretionary.* Dendrites, or dendritic forms, are those which have more or less the shape of a branching shrub or tree, as the forms of manganese oxide (Fig. 142) often seen on surfaces of smooth limestone or inclosed in moss-agates. Some dendritic forms are made up of little crystals grouped together in parallel position as remarked on p. 61.

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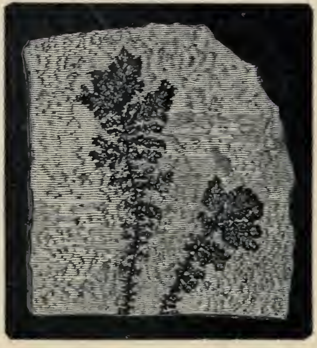


CHAPTER IV.

THE OTHER PHYSICAL CHARACTERS OF MINERALS.

Besides the external form of minerals shown in the crystals there are also a series of other physical characters, based (1) upon the molecular force of cohesion, (2) upon density, and (3) upon the action of light; also other characters of less frequent use, depending upon heat, electricity, magnetism; finally, a few minerals have distinctive characters of taste and odor.

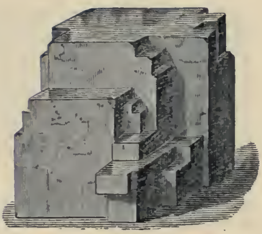
1. Characters depending upon Cohesion.

The characters depending upon the molecular force of cohesion will be described first. These include the cleavage, fracture, hardness, tenacity, and elasticity.

Cleavage.

The forms of crystals, as has been repeatedly stated, depend upon their molecular structure; but this internal structure reveals itself also by the cleavage, or the natural easy fracture which yields more or less smooth faces in certain definite directions. A cleavage surface marks a direction in which the force binding the molecules together is relatively weak. Thus galena is said to have *cubic cleavage* because its molecules separate readily in a direction parallel to each pair of parallel cubic faces; in other words, when fractured it breaks into a multitude of little cubes (Fig. 143). Fluorite, or fluor-spar, has *octahedral cleavage,* since the separation of the molecules is easy parallel to each pair of octahedral faces; hence from a single mass we may with care break out an octahedron. This cleavage octahedron, by the way, is readily distinguished by careful examination from a real octahedral *crystal,* because the faces are uneven and splintery, not uniform like the normal faces of a crystal. Even when the faces of a crystal are rough and uneven, they are quite different from the surfaces formed by cleavage, however perfect.

143.

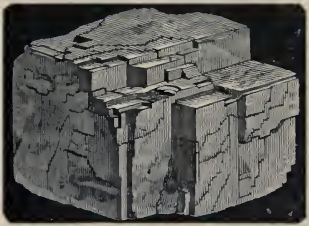


Cubic Cleavage—Galena.

The octahedral cleavage of fluorite is also seen in the case of a cubic crystal, since its solid angles may be easily broken off, giving a form like Fig. 107 on p. 50, which we have learned is a cubic modified, or with its angles replaced, by the planes of an octahedron. Again, from a piece of sphalerite or zinc blende a dodecahedron may sometimes be broken out because of its perfect *dodecahedral cleavage;* or if this is difficult because the fragment having like cleavage directions is too small, the skillful observer can yet prove that the cleavage-faces have the position of dodecahedral planes and make angles of 60° and 120° with each other. Further, a piece of calcite breaks readily into a number of rhombohedrons, all of the same angle, and it is hence said to have perfect *rhombohedral cleavage* (Fig. 144).

In the same way we find that amphibole has *prismatic cleavage;* mica has highly perfect *basal cleavage* or cleavage parallel to the end or basal plane, yielding excessively thin sheets; topaz has also basal cleavage. Gypsum has perfect cleavage parallel to the side plane of the crystal, yielding plates almost as thin as those of mica; these plates show two other cleavages on the edges, but different in character from each other, as is more fully described under the description of this species. Feldspar shows two cleavages, both nearly perfect but one a little more so than the other, and these make an angle of 90° or nearly 90° with each other. All these are cases of perfect cleavage, and it will be at once seen how important a character the cleavage is.

144.

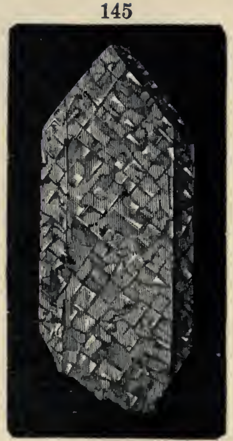


Rhombohedral Cleavage—Calcite.

But the cleavage is not always perfect, as in the examples given; sometimes it is obtained with difficulty, or the surfaces yielded may be only partially smooth; in such cases it is said to be imperfect, or interrupted, or difficult. Occasionally cleavage exists in cases where it is so hard to obtain that it is ordinarily not noted at all. Thus crystallized quartz usually shows only a conchoidal fracture, and the absence of cleavage is a character which at once distinguishes it from the feldspar with which it is often associated; yet a crystal of quartz which after being heated has been plunged into cold water often shows cleavage parallel to the pyramidal planes, perhaps also parallel to the prism. Cleavage-rifts in these directions are sometimes seen in natural crystals.

It is a help to remember that, even if a crystal does not actually show broken surfaces, the cleavage is often clearly indicated by a fine pearly luster on the face of the crystal parallel to it. This is seen on the basal plane of apophyllite, on the side plane of stilbite, and in many other cases. This pearly luster is due to the presence of cleavage rifts, though the crystal has not actually parted, just as a pile of thin glass sheets shows a pearly luster on top because of the repeated reflections. Similarly the cleavage rifts can often be seen in a transparent crystal; a flat clear crystal of barite or of celestite (Fig. 145) often shows the prismatic cleavage in two directions making an angle of about 104° with each other.

145



A massive specimen of a mineral may show cleavage as a multitude of little smooth faces changing position with that of the grains to which they belong; if these grains are very small, the cleavage may appear only as a fine spangling of the surface, as was mentioned on p. 66.

Fracture.

The nature of the surface given by fracture, when not the smooth surface of cleavage, is often an important character to note, especially in distinguishing the varieties of a mineral species. Thus glass, as well as quartz and many mineral species, shows a shell-like fracture surface which is called *conchoidal* (Fig. 146), or, if less distinct, small conchoidal, or subconchoidal.

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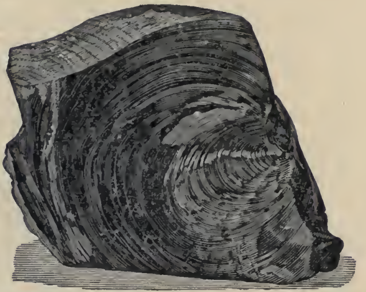

Conchoidal Fracture—Obsidian or Volcanic Glass.

More commonly the fracture is simply said to be *uneven*, when the surface is rough and irregular. Occasionally it is *hackly*, like a piece of fractured iron. *Earthy* and *splintery* are other terms sometimes used and easily understood.

Hardness and Tenacity.

By hardness the mineralogist understands the degree of resistance which the smooth surface of a mineral offers to a point or edge tending to scratch it. A diamond easily makes a scratch on a smooth topaz crystal; the topaz scratches a quartz crystal, while the quartz scratches a glass surface, and the glass in turn scratches one of calcite. This means that each substance named is harder than that which it scratches, or, in other words, softer than the one by which it is scratched.*

Mineralogists have found it convenient to select a number of minerals for the comparison of hardness, and they are designated by the numbers from 1 to 10, as given in the following list. Crystallized varieties are to be taken in each case, that is, a crystal with even surfaces or a smooth cleavage fragment.

1. Talc.
2. Gypsum.
Rock Salt → Thumb Nail
3. Calcite.
4. Fluorite.
5. Apatite.
Knife
6. Orthoclase.
7. Quartz.
8. Topaz.
9. Corundum.
10. Diamond.

When it is said that the hardness of a mineral is 4, this means that it is scratched as easily as fluorite, for example by a mineral which follows in the list, while it will itself scratch all of the minerals which precede. If the hardness of a mineral is given as 5.5, this means that it is a little harder than apatite and a little less hard than orthoclase.

The student should practise with the minerals in this scale up to topaz or corundum, and then with them experiment upon some other known minerals, until he learns just what degree of hardness each of the numbers corresponds to, especially those up to 7. He ought soon to become so proficient as to be able to determine the lower grades of hardness by his knife without the use of the reference species at all.

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* In general a faint scratch can be made on the surface of a crystal by the edge of another of the same species; this is readily proved with quartz.

He will find at once the following general distinctions between minerals of the several grades:

No. 1: has a soft, greasy feel in the hand, like talc and graphite.

No. 2: can be scratched easily by the finger-nail, as a cleavage-piece of gypsum.

No. 3: can be easily cut by the knife, but is not scratched by the nail.

No. 4: is scratched by the knife without difficulty, but not easily cut like calcite.

No. 5: is a little hard to scratch with a knife.

No. 6: is hardly touched if at all by the knife, but it will scratch ordinary glass.

No. 7: scratches glass easily, but is scratched by topaz and a few other minerals mentioned in the list given in Chapter VIII. The minerals which are as hard as or harder than quartz are few and include all the highly-prized gems. Some further notes on hardness are given in connection with the list referred to.

The beginner will need a word of advice in regard to testing for hardness. In the first place treat a mineral, especially a crystal, with as much consideration as possible. A scratch on a piece of plate-glass, like a daub with a paint-brush on a white wall, is a little thing, but it may have a sadly disfiguring effect and make a pane worth when new a thousand dollars unsalable except to be cut up. So a scratch on a crystal disfigures it and destroys its value in large measure in the eyes of one who is a true mineralogist. Hence make as minute a scratch as possible, not longer than this —, and if possible put the scratch, *not* on the most prominent surface, but where it will show least. Treat the crystal, then, as if it had feelings to be hurt by the cut, and never scratch its smooth surface wantonly, nor if it is possible to obtain the desired information without it.

On the other hand, it is necessary to be sure and distinguish between a real scratch on a smooth surface and the crushing of a rough surface by the knife-edge; a very hard mineral may often be scratched in this way. The danger of making a mistake of this kind is made less if, besides the useful knife-point, the mineral be rubbed on a piece of glass; better have a piece at hand (not disfigure a window-pane). Only do not make the opposite mistake and call a white ridge left by a soft mineral on the glass, which can be easily rubbed off, a scratch.

Once more, it is necessary to remember that minerals are often altered, as the chemist says; that is, they may have undergone some chemical change, particularly on the surface, which has rendered that soft when the original mineral was really hard. Thus it is often easy to make a scratch on a crystal of corundum because of a little surface change, while the mass within is very hard. If the mineral is used to scratch with, the danger of a mistake here is lessened.

There are also some other characters depending upon the force of cohesion acting between the molecules of a mineral. These include the following, which are sometimes grouped under the general head of TENACITY:

Malleable: capable of being flattened out under the blow of a hammer without breaking or crumbling into fragments. This is conspicuously true of gold and silver, and makes it possible to beat out gold into leaves of extreme thinness. The property of malleability belongs only to the native metals and, in an inferior degree, to a few compounds of silver.

Ductile: capable of being changed in shape by pressure, especially of being drawn out into the form of wire. This is true of gold, also still more of silver and platinum. It is a property which belongs in a high degree only to the native metals among minerals.

Sectile: capable of being cut by a knife like cold wax, so that a shaving may be turned up with care, and yet the mineral breaks with a blow, and is not properly malleable, sometimes not at all so. Cerargyrite is eminently sectile. Gypsum and a number of soft minerals are imperfectly sectile. No sharp line separates the minerals which show these characters and the truly brittle minerals.

Flexible: the mineral bends easily, and stays bent after the pressure is removed. This is shown in talc.

Brittle: separating into fragments with a blow or with a cut by a knife. This is true, in varying degrees, of nearly all minerals.

The elasticity is another physical character based upon cohesion. A mineral is said to be

Elastic when it is capable of being bent or pulled out of shape and then returning to its original form when relieved, as a plate of mica. On the other hand, a cleavage-plate of chlorite is inelastic.

2. SPECIFIC GRAVITY OR RELATIVE DENSITY.

It has been shown that the eye-examination of a mineral tells the observer something about its form, if crystallized, and of its structure in other cases; it tells whether it has cleavage or not, and with what kind of surface it breaks; a simple trial also shows how hard it is. At the same time, as it rests in the hand, it should be noted whether it seems distinctly heavy or light as compared with some common substances of similar appearance. In this way a first suggestion is obtained,—not exact and, as we shall see, not always correct—as to the *density* of the mineral.

It is necessary at the outset to have a pretty clear notion as to what a difference in density means. Suppose two doors of just the same size, and both swung carefully on hinges so that they move almost without friction, but one of wood, the other of iron. Every one knows that the force required to push the iron door will be much greater than that which the other requires. Again, a kick against a wooden ball resting on the ground encounters more resistance than against a ball of paper, but less than one of stone. These experiments show that in a piece of iron there is more matter to move,—it has a greater mass for the same bulk than the wood. In other words, it has a *greater density.* This is generally expressed by saying that the weight of the iron is greater than of the wood of the same size, and this is true because the attraction of the earth, which gives an iron ball its weight, is in proportion to the mass or, for different bodies of the same size, to the density.

We may say, consequently, that the relation of the densities of different bodies is given by the weights of blocks having the same bulk. Suppose we could cut out like blocks of aluminium and iron and weigh them, the weights would be not far from the ratio of 1 to 3, and this would be the relation in density. Now to make this comparison for all bodies, it is evidently important, in the first place, to choose some one of them as the standard, and make the comparison with this.

The standard substance adopted is pure water, and, if great accuracy is required, this must be taken at the temperature 39°.2 F. (4° Centigrade), where it has its maximum density; for water, if growing cooler or warmer than 39°.2 F., expands a little and grows less dense. The density of minerals is then compared with water, and this density is called the *specific gravity*. Consequently the specific gravity of a mineral may be stated to be the weight of a fragment divided by that of an equal volume of water. The specific gravity of sulphur is 2, of corundum 4, of pyrite 5, etc., these numbers meaning that they are respectively 2 times, 4 times, and 5 times as dense as water, or, in other words, a given bulk—a cubic foot, for example—weighs 2, 4, and 5 times more than the same bulk—a cubic foot—of water.

In order to find the specific gravity, it is not practicable to compare at once the weights of equal volumes, simply because (though it is easy to weigh, for example, a piece of calcite) it is not possible to get its volume with sufficient accuracy. Hence it is necessary to make use of a well-known principle in hydrostatics, that when a body is immersed in a liquid it is buoyed up by the liquid, and to such an extent that it weighs, for example in water, less than it does in the air by the weight of the water it displaces. Hence, if we find first the weight of the fragment on the pan of a delicate balance, and then its weight in the water, it being suspended from the pan by a fine thread, and subtract the two weights, the difference is the weight of the equal volume of water.

For example, the weight of a little quartz crystal is 3.455 grams in the air; in the water it is 2.156; the loss of weight, or weight of a volume of water exactly equal to it, is therefore 1.299; hence the specific gravity is

$$\frac{3.455}{3.455 - 2.156} = \frac{3.455}{1.299} = 2.66.$$

In the description of species the specific gravity is often expressed by the initial letter G; thus for a quartz crystal $G = 2.66$.

A spring-balance* like that of Jolly makes the operation very easy. This consists of a delicate brass spring, one end of which is attached to the top of a vertical scale, and from the other hang two pans, the lower one of which is immersed in water. The small fragment whose specific gravity is to be determined is placed in the upper pan, and the amount that the spring is stretched noted by the number (N_1) coinciding with the reflection of an index in a strip of mirror upon which the scale is graduated; then in the lower pan, and the scale number (N_2) again noted; the number (n) when the pans are empty is also observed. The specific gravity is then given by the expression

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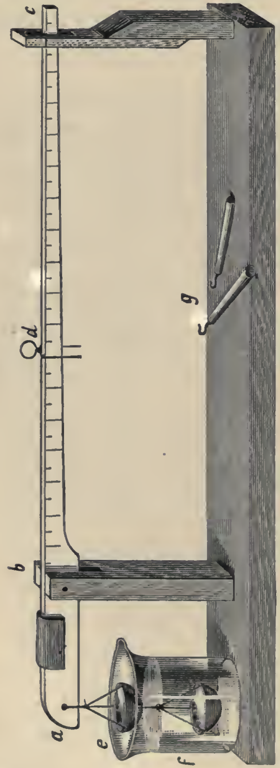
* This is figured on page 69 of Dana's Manual of Mineralogy, 1887.

$$G = \frac{N_1 - n}{N_1 - N_2}.$$

In this case we do not have the actual weights given, but numbers which are proportional to them.

A simple balance for determining the specific gravity, which also does away with the necessity of using definite weights, is shown in Fig. 147 (one sixth natural size), and can easily be constructed* with a little care. After the frame is made with the two uprights, a thin piece of wood is cut in the form of the steelyard beam, *abc*. This should be graduated into inches† and tenths of inches from *b*, the axis, to the end *c*; the distance from *b* to *a*, where the pans are supported, being made 4 inches. A fine wire passed through at *b* answers as the axis, and the pans are



147.

Balance for Specific Gravity. Scale one sixth.

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* The author is indebted to Prof. Penfield for the opportunity to figure and describe this balance.

† The metric scale may be conveniently used instead.

also held by wires, best of platinum; the lower pan is immersed in water. A small piece of lead permanently placed between *b* and *a* serves to counterpoise the long arm, and a little rider is first moved to some point, as *d*, where it serves to make *bc* exactly horizontal, as shown by the mark on the upright near the end *c*. A number of weights (as from $\frac{1}{4}$ to $1\frac{3}{4}$ grams) are further needed; these may be easily made of soft copper wire bent with a hook at one end, or they may be little glass tubes containing 1, 2, 3 or more shot and with a wire hook fused in at one end (see those at *g*). The fragment* experimented upon is first placed in the pan *e*, a suitable counterpoise chosen, and the number (N_1) on the scale where it must be placed to make *bc* again horizontal recorded; it is then transferred to the pan *f*, immersed in the water, and the scale number again noted (N_2), the *same* counterpoise being employed. The first number then divided by the difference of the two numbers gives the specific gravity:

$$G = \frac{N_1}{N_1 - N_2}.$$

For example, a small pyrite crystal is placed in the pan *e*, and a counterpoise chosen which balances the beam when placed 14.45 inches from *b*; the crystal is then transferred

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* A fragment or crystal as heavy as 7 grams may be employed with the weights mentioned; but it should be understood that it is not necessary to know the actual weight either of the fragment or of the counterpoise; thus if the actual weight of the counterpoise is C, and of the mineral in air and in water W_1 and W_2 respectively, then, using the numbers N_1 and N_2 as above, we shall have

$$W_1 \times 4 = C \times N_1 \quad \text{and} \quad W_2 \times 4 = C \times N_2; \text{ that is, } \frac{W_1}{W_2} = \frac{N_1}{N_2}.$$

to the pan f, which requires that this counterpoise should be moved back to 11.55 inches. The specific gravity is thus found to be

$$\frac{14.45}{14.45 - 11.55} = \frac{14.45}{2.9} = 4.98.$$

It is evident that the accurate determination of the specific gravity is a somewhat difficult matter, requiring a good deal of care, but, as was suggested at the beginning, the hand can often give very valuable information in this direction after a little training. We are accustomed to handle fragments of rocks, as of granite (specific gravity about 2.7), of marble (specific gravity = 2.7), and of other like substances, and we know about what to expect as to the weight of them; hence if we pick up a piece of barite or heavy spar, perhaps thinking it is marble, which it may resemble so closely that the unaided eye cannot distinguish them, we notice or ought to notice at once that it is unexpectedly heavy, for its specific gravity is 4.5. So a piece of corundum, we say, feels heavy because it has a specific gravity as high as 4. This last, by the way, is an interesting case, because corundum is the oxide of the very light metal aluminium, and its relatively high density is connected with its great hardness; in other words, it is evident that its molecules must be much crowded together. In the same way we note that the substance carbon forms the *hard* and relatively *heavy* * mineral diamond (specific gravity = 3.5) and the *soft* and *light* mineral graphite (specific gravity = 2). In other words, the density depends not only upon the kind of molecules (all lead compounds, for example, have necessarily a high specific gravity), but also upon the way they are built up together.

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* In these statements, as in some similar cases, the word *heavy* is used instead of dense, that is, of high specific gravity, and also the word *light* to express the opposite character; the meaning will be clear even if these terms are not quite scientifically employed.

Again, if we take up a metallic mineral, we compare it, perhaps without conscious thought, with other common metallic substances. Hence a piece of aluminium seems very light, because the specific gravity is only 2.5, about one *third* that of iron and less than one quarter that of silver. On the other hand, a fragment of galena seems heavy because its specific gravity is 7.5, or nearly equal to that of metallic iron.

When we come to study minerals we find that they divide themselves as follows:

I. *Minerals of Unmetallic Luster.**—These may be roughly subdivided into three classes:

1. Minerals of relatively *low* density; the specific gravity not higher than 2.5. Examples are as follows (here G. = specific gravity):

	G.		G.
Borax..........	1.7	Stilbite..........	2.2
Sulphur.........	2.05	Gypsum.........	2.3
Halite	2.1	Apophyllite	2.4

The zeolites (as stilbite above) mostly fall between G. = 2.0 and G. = 2.3.

2. Minerals of *average* density: specific gravity 2.6 to 3. Common examples are:

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* This matter of luster is more definitely spoken of on a later page of this chapter.

	G.		G.
Quartz	2.66	Feldspar	2.6–2.75
Beryl	2.7	Talc	2.8
Calcite	2.7	Muscovite	2.8

The scapolites (G. = 2.5–2.8) also belong in this group.

The common minerals tourmaline (G. = 3.0–3.2), apatite (G.= 3.2), vesuvianite (G.= 3.4), amphibole (G.= 2.9–3.4), pyroxene (G.= 3.2–3.6), epidote (G.= 3.25–3.5) fall between this and the following group. Some varieties of garnet also belong here; others have a specific gravity up to 4.3.

3. Minerals of *high* density: specific gravity 3.5 or above; a fragment seems *heavy* in the hand; if the specific gravity is above 4.5, it seems very heavy.

	G.		G.
Topaz	3.5	Witherite	4.3
Diamond	3.52	Barite	4.5
Staurolite	3.7	Zircon	4.7
Strontianite	3.7	Scheelite	6.0
Celestite	3.96	Cassiterite	7.0
Corundum	4.0	Wolframite	7.5
Rutile	4.2	Cinnabar	8.0

The compounds of lead also belong here, the commonest of which are: cerussite, the carbonate; anglesite, the sulphate; and pyromorphite, the phosphate. They all have a specific gravity between 6 and 7. Compounds of iron (as siderite, G. = 3.8), of copper (as cuprite, G. = 6.0), of silver (as cerargyrite, G. = 5.5), and of the other heavy metals have also high specific gravities.

II. *Minerals with Metallic Luster.*—The average is about 5, the specific gravity of pyrite and hematite. If the density is much lower than 4, the mineral seems light in the hand, as graphite (G. = 2). If the density is as high as 7, or above, they seem notably heavy, as galena, 7.5. Crystallized uraninite, which has a submetallic luster, has the remarkably high specific gravity of 9.7 when unaltered. The variation is wider in the case of the metallic minerals than with those of unmetallic luster, as will be seen by comparing the following densities of the common metals:*

Aluminium	2.5	Bismuth	9.8
Arsenic	5.7	Silver	10.6
Antimony	6.7	Lead	11.4
Zinc	7.1	Mercury (liquid)	13.6
Tin	7.3	Gold	19.3
Iron	7.8	Platinum (pure)	21.5
Copper	8.9		

The quick judgment which comes with practice is always of value, but it should be applied with discretion, for the mineralogist must be continually on his guard lest he be misled.

In the first place, the size of the mass is an important factor, for a big lump of quartz seems heavy, of course, though its specific gravity is not relatively high. Also we

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* It is interesting to add the following, although these metals do not exist as such in nature, and are only interesting to the chemist:

Lithium	0.59	Sodium	0.97
Potassium	0.86	Magnesium	1.8

may get a wrong impression in handling a specimen if the mineral we are interested in only forms a small part of it; a little galena in a large mass of quartz will not make it heavy. Also, if the mineral is open and porous, and is made up of interlacing fibers, like some specimens of cerussite, it may appear light, even if the specific gravity is actually high, because the eye is deceived by the appearance of bulk, while the solid mass present is not great. Some further suggestions on this subject are given in the closing chapter of this book.

3. CHARACTERS DEPENDING UPON LIGHT.

Of the characters which are observed by the eye several have not been mentioned in detail as yet, to which perhaps the attention may be first attracted. These are those which depend upon the reflection or absorption of the light: (1) the *luster* or the appearance of the surface independent of the color, due to the way the light is reflected; (2) the *color;* and (3) the degree of *transparency*.

Luster.

The difference in luster is not in all cases easy to describe, but the eye notes it at once, and after a little training seldom makes a mistake.

The kinds of luster distinguished are as follows:

Metallic: the luster of a metallic surface as of steel, lead, tin, copper, gold, etc. This is not always easy to distinguish, and the rule is an important one that the luster is not called *metallic* unless the mineral is quite *opaque,* so that no light passes through even very thin edges. The luster of some minerals, as columbite, is said to be *submetallic* when it lacks the full luster of the metals. In a few cases a mineral has varieties with metallic and others with unmetallic luster; this is true of hematite.

Vitreous, or glassy luster: that of a piece of broken glass. This is the luster of most quartz and of a large part of non-metallic minerals.

Adamantine, or the luster of the diamond: this is the brilliant, almost oily, luster shown by some very *hard* minerals, as diamond, corundum, etc.; also of some others, having *heavy* molecules, as the carbonate (cerussite) and the sulphate (anglesite) of lead. All of these refract the light strongly, or have a high refractive index.

Metallic-adamantine is a term used to describe a variety of the adamantine luster verging upon metallic, as seen in some dark-colored varieties of cerussite.

Resinous or waxy: the luster of a piece of rosin, as that of most kinds of sphalerite or zinc blende; near this, but often quite distinct, is *greasy luster,* shown by some specimens of milky quartz.

Pearly, or the luster of mother-of-pearl: this is common where a mineral has very perfect cleavage and hence has partially separated into thin plates. Thus the basal or top plane of crystals of apophyllite shows pearly luster.

Silky, the luster of a skein of silk or a piece of satin: this is characteristic of some minerals with fibrous structures, as the variety of calcite (or of gypsum) called satin spar; also of most asbestus.

The luster of minerals is also described according to the brightness of the surface; it is called *splendent* in freshly fractured galena, but *dull* in jasper; while again it may be glistening or glimmering according to the nature of the surface. These terms explain themselves.

Color.

To understand what the *color* of a mineral means a little knowledge of optics is required. In the first place, we must recall that ordinary light can be separated, as by a glass prism, into the ribbon of colors ranging from the red to the blue and violet which is called the spectrum. This is shown in the rainbow, where the place of the prism is taken by the raindrops. All these different colors together give to the eye the effect of white light. If now this white light, as the ordinary sunlight, be passed through a piece of red glass or reflected from a surface of red paint, part of the colors are stopped or absorbed by the glass or paint and the rest give together the effect of red which the eye notes. Similarly a piece of malachite appears green for the same reason that the grass does, because the surface absorbs a part of the light, and the remainder which reaches the eye gives to it the effect of green.

The variation in color is very wide and includes all kinds from white to black, running through many shades of red, yellow, green, and blue. Most of the terms used in describing the color are so familiar that they explain themselves. Thus we speak of azure-blue, cherry-red, and so on. Some examples of color among common minerals are given in Chapter VIII.

Now a few words as to the importance of color and the extent to which it may vary with the same species.

As we go on to study the different mineral species we learn that the varieties of those with *metallic luster* do not vary much in color among themselves. Many of the other minerals, however, which do not have a metallic luster vary very widely; and in the same species, as tourmaline, we may have colorless kinds, also those that are different shades of red, blue, green, brown, and black.

So too we call clear red kinds of corundum *ruby*, and clear blue kinds *sapphire*, although they both belong to the same mineral; and in this as in many other cases it is difficult to tell precisely what is the very slight chemical change upon which the color depends.

In general, therefore, the color of minerals with metallic luster is a very important and constant character, and such variations as are noted are due chiefly to a little change of the surface, by which it becomes tarnished, as we say; that is, dull in some cases, or perhaps bright-colored in others. Thus galena has a very characteristic bright bluish lead-gray color, which, however, may become quite dull if the surface has been long exposed to the air. Again, the pale brass-yellow of pyrite and the still paler shade of the same color characteristic of fresh marcasite are readily distinguished, but both are subject to tarnish, especially the latter, and this may result in making the distinction between the two impossible in the case of exposed surfaces.

Hence it is necessary to be on our guard to insure that what we see is the true color of a mineral, that is, the color which is obtained from a fresh surface by fracture.

Another striking example is given by the mineral bornite, which has a very peculiar reddish-bronze color on a fresh surface, on account of which the miners of Cornwall have called it horse-flesh ore. But this changes or tarnishes so easily that it almost immediately becomes colored bluish, purple, etc., the color depending on the time it has been exposed. Because of this character the mineral is sometimes called purple copper ore or variegated copper ore. So too chalcopyrite, which is bright brass-yellow when fresh, may become iridescent as in the variety called peacock ore—a name which, by the way, is also given to bornite.

It is often important, especially with a mineral having metallic luster, to test the color of the fine powder, or the color of the *streak*. The slight scratch which is given to test the hardness will often show this, but a better way is to have at hand a piece of rough white porcelain, or one of ground glass upon which the mineral can be rubbed. This method shows, for example, that hematite, sometimes iron-black in color and with a bright metallic luster, has a *red streak;* this is indeed so important a character that it is the source of the mineral's name (from the Greek *αἷμα*, meaning *blood*).

Minerals of unmetallic luster usually have a streak which differs but little from white even if the mineral itself is dark-colored or even black; this is true, for example, of the different varieties of tourmaline.

Transparency.

A mineral is said to be *transparent* when it is so clear that an object can be seen through it with perfect distinctness, as a piece of window-glass, a plate of selenite, or a thin sheet of mica. It is *semi-transparent* or *subtransparent* when the outlines of an object can be seen, but not distinctly.

A mineral is *translucent* when it transmits light, as a piece of thin porcelain, but does not allow an object to be seen through it. It is *subtranslucent* when light is transmitted only on the edges.

When describing the color of a mineral, some peculiarities in its distribution may be noted and receive special names. A mineral is said to show a *play of colors* when, like the opal, it exhibits internally the various prismatic colors when the mineral is turned.

A pearly reflection from the interior of a mineral, like the effect of a glass of water to which a few drops of milk have been added, is called *opalescence* because common with the opal.

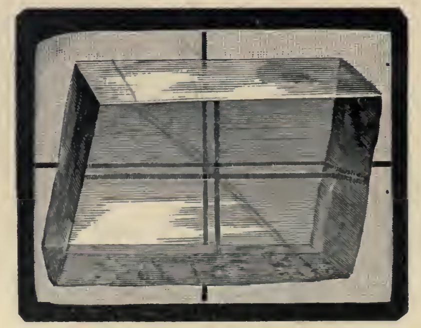
Iridescence is the presenting of prismatic colors on the surface of a specimen, and then usually due to tarnish; or in the interior of a mineral, and then often explained by the presence of thin twinning lamellæ or of minute air-spaces, as in a cleavage mass of calcite.

Asterism is the name given to the peculiar starlike effect seen sometimes by reflected light, as in certain kinds of sapphire; or by transmitted light, as in some mica when a candle-flame is viewed through it. It is due in the first case to planes of structure intersecting symmetrically in the crystal; in the second to the presence of minute crystals of a foreign mineral (often rutile) symmetrically arranged between the plates of the mica.

Phosphorescence is the property of becoming luminous when slightly heated, as shown by fluorite, especially the variety chlorophane; also upon friction, as some marble, tremolite, etc.; again, when exposed to the sun-rays or to an electric discharge, this last being especially true of some of the gems.

Optical Characters.—Only a few words can be devoted here to the large and important class of *optical characters* of minerals, depending upon the action of light on them as determined by their molecular structure. The understanding of this part of Physical Mineralogy demands first a good knowledge of crystallography, and further a mastery of optics, especially of the difficult subject of polarization. Only one or two points belonging here can be touched upon.

148.



Iceland Spar or Double refracting Spar.

One of these is *double refraction*, or the separation of a ray of light passing through certain crystalline substances into two rays. This is indeed true, in general, of all transparent crystals, except those of the isometric system, but the only mineral in which it is noted to a marked degree is calcite, especially in the transparent variety called Iceland spar. Fig. 148 illustrates this property well; there the single cross on the paper beneath appears double to the eye; one cross (to the eye looking perpendicularly down on the surface) has its arms in the continuation of the lines beneath, the other is pushed to one side. Neither cross appears quite black except at the two points where they intersect.

Another point in this connection is the *dichroism* of a crystal, or the appearance of different color, as it is viewed by transmitted light in different directions; this is due to varying degrees of light absorption. This is often seen in transparent crystals of epidote; it is also to this cause that the different appearance of a crystal of muscovite is due, first, in the direction through it and again at right angles to the cleavage.

4. CHARACTERS DEPENDING UPON HEAT.

The fusibility of minerals, or their relative power of being melted at a more or less elevated temperature, is the most important character depending upon the action of heat. This is discussed in another place in connection with the description of the use of the blowpipe. The conductivity of crystals for heat is another point which sometimes is experimented upon. As would be expected, it depends upon their molecular structure in different directions. This and other related subjects belong to advanced mineralogy.

5. CHARACTERS DEPENDING UPON MAGNETISM.

A few minerals have the property of being attracted by a magnet. This is true of magnetite, or the magnetic oxide of iron; of pyrrhotite, or magnetic pyrites; also of some specimens of native platinum.

A specimen of magnetite sometimes is itself a magnet, and has then the power of attracting little particles of iron or steel; it has a north and south pole, and if hung by a thread will swing around until the poles come into the magnetic meridian, that is, the direction assumed by a compass-needle. This kind of magnetite is called the *lodestone.* Pyrrhotite is much less strongly magnetic than magnetite, and the magnetic varieties of platinum are not common; both may have polarity like the lodestone. A few minerals, as hematite and franklinite, are sometimes slightly magnetic, but probably only because they contain a little admixed magnetite.

Most minerals containing much iron become magnetic when heated in the reducing-flame of the blowpipe; this is true also of millerite or the sulphide of nickel.

6. CHARACTERS DEPENDING UPON ELECTRICITY.

There are a number of electrical properties of minerals, but these are characters that belong to a more minute study of minerals, and they need be only briefly mentioned here.

A number of minerals, like sulphur, the diamond, and topaz, become rather strongly electric when rubbed, as with a piece of silk, and show this by their power of attracting light substances, such as bits of straw or paper. Again, the crystals of some minerals, when carefully heated or cooled, become electrified and show opposite kinds of electricity in different parts, as at the two extremities; this is particularly true of tourmaline. It is remarked on p. 318 that when both ends of a tourmaline crystal are developed it is common to find them different in their crystalline faces. This dissimilarity in structure in the opposite directions of the axis is connected with the property of becoming dissimilarly electrified by change of temperature. This subject is called *pyro-electricity,* because the electrical effect is due to the action of heat (πῦρ, *fire*). Tourmaline is hence said to be *pyro-electric,* and the same is true of quartz, and less strikingly of many other species.

7. TASTE AND ODOR.

Taste belongs only to the few minerals which dissolve to some extent in water. The terms employed are familiar and hardly need explanation. *Saline* means the taste of common salt; *alkaline,* of soda; *bitter,* of epsom salts; *sour,* of an acid; *astringent,* of iron vitriol; *sweetish astringent,* of alum; *cooling,* of saltpeter.

Odor also belongs to a few minerals only. Some varieties of limestone, barite, or quartz have a *fetid* odor, or odor of rotten eggs, especially if rubbed sharply; this is usually due to the presence of some sulphur compound. Moistened clay and some *claylike* minerals when breathed upon give off a peculiar *argillaceous* odor. Bitumen and some allied substances have a *bituminous* odor.

A sharp blow across the surface of a piece of arsenopyrite often produces a peculiar garlic odor, like that obtained by heating the same mineral on charcoal, and in fact due to the same cause. Similarly a blow on a mass of pyrite may yield a *sulphurous* odor

CHAPTER V.

THE CHEMICAL CHARACTERS OF MINERALS.

It has already been stated that every mineral is necessarily a *definite chemical compound,* and that this is the most essential point in the definition of a mineral. But to understand what a chemical compound is, and what relations different compounds bear to each other, requires some knowledge of the fundamental principles of chemistry. In the first place it is necessary to understand what the *chemical elements* are.

The chief work of the chemist in the laboratory is to *analyze* different substances, or in other words to separate them into the various kinds of matter which they contain. But this process of analysis, or chemical separation, can only be carried a little way, for the chemist soon obtains substances which he is unable to decompose further. Thus if he takes a piece of calcite, it is easy by simply heating it to separate it into a white powder called lime (this is what the mason uses for making mortar) and a gas called carbon dioxide, or carbonic-acid gas. Then further, if the proper means are taken, the lime can be separated into a metal, called calcium, and a gas, oxygen; while the carbon dioxide can be separated into the familiar substance carbon and the same gas, oxygen. But these three substances, calcium, carbon, oxygen, cannot be decomposed further; hence they are called elementary substances or elements. Again, common salt can be separated into two kinds of matter, the metal sodium and the gas chlorine; but neither of these can be separated any further, hence they are also put down among the simple or elementary substances. So, too, galena can be separated into its elements, the metal lead and sulphur; sugar is decomposed into carbon and the gases hydrogen and oxygen; and many other illustrations might be given.

These substances, then, into which a given kind of matter can be separated, but which the chemist is unable to decompose further, are the CHEMICAL ELEMENTS.

Now the chemist finds that although there is no limit to the different kinds of bodies which he may be asked to analyze or separate into their parts, still they contain but a small number of distinct kinds of matter. If we regard only those which are commonly present, they are very few indeed. There are, it is true, about seventy of the elements recognized by the chemist, but many of them are excessively rare, and those which make up the chief part of common minerals are hardly more than twelve or thirteen.

The table, p. 101, gives the names of all the common elementary substances and most of the rarer ones. With the names are given also the initial letter or letters by which they are generally represented in the kind of algebraic shorthand that the chemist employs; these letters are called the *symbols* of the elements. Thus oxygen is represented by the capital letter O; hydrogen by H; nitrogen by N; calcium by Ca; and so on. In a good many cases the

THE CHEMICAL ELEMENTS.

	Symbol.	At. Weight.
Aluminium	Al	27
Antimony (*Stibium*)	Sb	120
Arsenic	As	74.9
Barium	Ba	137
Beryllium	Be	9.1
Bismuth	Bi	207.5
Boron	B	10.9
Bromine	Br	79.8
Cadmium	Cd	111.7
Cæsium	Cs	58.7
Calcium	Ca	39.9
Carbon	C	12
Cerium	Ce	141
Chlorine	Cl	35.5
Chromium	Cr	52.5
Cobalt	Co	58.7
Columbium, see *Niobium*.		
Copper (*Cuprum*)	Cu	63.2
Didymium	Di	142
Erbium	Er	166
Fluorine	F	19.1
Germanium	Ge	73.3
Glucinum	Gl or Be	*
Gold (*Aurum*)	Au	196.7
Hydrogen	H	1
Iodine	I	126.5
Iridium	Ir	192.5
Iron (*Ferrum*)	Fe	55.9
Lanthanum	La	138
Lead (*Plumbum*)	Pb	206.4
Lithium	Li	7
Magnesium	Mg	24
Manganese	Mn	54.8
Mercury (*Hydrargyrum*)	Hg	199.8
Molybdenum	Mo	96
Nickel	Ni	58.6
Niobium	Nb	93.7
Nitrogen	N	14
Osmium	Os	191
Oxygen	O	16
Palladium	Pd	106
Phosphorus	P	31
Platinum	Pt	194.3
Potassium (*Kalium*)	K	39
Rhodium	Rh	104.1
Rubidium	Rb	85.2
Ruthenium	Ru	103.5
Scandium	Sc	44
Selenium	Se	78.9
Silicon	Si	28
Silver (*Argentum*)	Ag	107.7
Sodium (*Natrium*)	Na	23
Strontium	Sr	87.3
Sulphur	S	32
Tantalum	Ta	182
Tellurium	Te	125
Thallium	Tl	203.7
Thorium	Th	232
Tin (*Stannum*)	Sn	117.4
Titanium	Ti	48
Tungsten (*Wolframium*)	W	183.6
Uranium	U	240
Vanadium	V	51 1
Ytterbium	Yt	172.6
Yttrium	Y	89
Zinc	Zn	65.1
Zirconium	Zr	90.4

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* See *Beryllium*.

initial letters of the Latin name of a metal are used, as Fe, from the Latin *ferrum*, for iron; Ag, from *argentum*, the Latin name of silver; Au, from *aurum*, gold; Sb, from *stibium*, antimony, etc.

The numbers placed after each name give the *atomic weight* of each element. What this is will be explained immediately. But first note that the larger part of the elements are *metals*, having physical properties of luster, malleability, etc., more or less like those of gold, silver, lead, and iron. There is also a small class of *non-metals*, including the gases, hydrogen, oxygen, etc., also sulphur, phosphorus, silicon, and carbon. Further, a few elements standing between the two groups are sometimes called *semi-metals*, as tellurium, arsenic, antimony. The chemical distinction between the metal and non-metal is spoken of later.

Now as to the meaning of the term *atomic weight*. We have spoken quite particularly of the minute particles, or molecules, of which the physicist believes that a body is made up, and whose relations to each other determine whether the body is a solid, a liquid, or a gas. We have also seen that the regular form of a crystal is due to the arrangement of these molecules as they are marshaled into place by the attractive forces acting between them when the solid is formed. Now these minute molecules, as the chemist believes, are made up of simpler particles, often of several different kinds of elements, which he calls *atoms*. It is the relative weight of the atom of each substance compared with that of the lightest substance known, hydrogen, that is called its *atomic weight*. This does not mean that the chemist can actually weigh the atoms themselves that form the minute molecules out of which a body is built up, but he can compare the weights of two masses, for instance of oxygen and hydrogen, under such conditions that he is sure that he is comparing the same number of atoms, and hence he obtains the relative masses of the atoms; or he may obtain the same result in one of several indirect ways.

It is found invariably true that when the different elements unite to form a certain compound, there is always a definite relation between the amounts by weight of each element which enters, and that these weights are either the atomic weights or simple multiples of them, as given by the number of atoms present.

Just what this means will be shown by some examples. It was stated above that the chemist could decompose common salt into sodium and chlorine. Now in doing this it is possible to find how much by weight of each is present, for instance, in 100 parts. The result is this:

Sodium	39.32
Chlorine	60.68
	100.00

But the numbers 39.32 and 60.68 are in the ratio of 23 to 35.5 (39.32 : 60.68 = 23 : 35.5), which have been independently found to be the atomic weights of these two elements, and hence it is evident that there is one part, or one atom, of each present in this compound. The brief expression for the composition of sodium chloride, or the *formula* as it is called, is NaCl, for Na is the symbol for sodium (*natrium*) and Cl of chlorine.

The *formula* of a compound, therefore, gives simply the kinds of elements present, represented by their initial letters, that is, by their symbols, with small numbers, written usually below, to show how many parts of each, that is, how many atoms, are present.

Again, calcium unites with chlorine also, and the compound, calcium chloride, analyzed by the chemist, gives:

Calcium	36.04
Chlorine	63.96
	100.00

Here the numbers 36.04 : 63.96, expressing the ratio by weight of the two substances, are in the ratio of 40 : 71 or 40 : 2 × 35.5; hence the compound contains one atom of calcium and two of chlorine, and the brief expression, or formula, for it is $CaCl_2$.

Two other examples are gold chloride and tin chloride, analyzed with the following results:

Gold	64.87	Tin	45.26
Chlorine	35.13	Chlorine	54.74
	100.00		100.00

For the gold chloride the ratio of 64.87 : 35.13 is as 196.7 : 106.5 or 196.7 : 3 × 35.5; hence the formula is written $AuCl_3$. Similarly for tin chloride the ratio of 45.26 : 54 74 is as 117.4 : 142 or 117.4 to 4 × 35.5; hence the formula is $SnCl_4$.

These examples illustrate the fact that the atomic weights of the given elements multiplied by the number of atoms gives the amount of each element present in the given compound. They also show another important point: it is seen that one atom of chlorine unites with one atom of sodium, but two atoms of chlorine with one of calcium, three with one of gold, and four with one of tin.

Again, in hydrochloric acid the formula can be shown to be HCl; in other words, one atom of hydrogen is present and one of chlorine. Water, however, has the formula H_2O, or contains in a molecule two atoms of hydrogen and one of oxygen; sulphureted hydrogen is similarly H_2S. In other words, one atom of chlorine is here, as always, equivalent to one of hydrogen, but one of oxygen or one of sulphur is equivalent to two of hydrogen.

Further, it is evident, from what has been stated, that the formula of galena, or lead sulphide, must be PbS, since one atom of lead unites with two atoms of chlorine, and one of sulphur is equivalent to two atoms of hydrogen or chlorine; therefore one atom of lead (Pb) is equivalent in combining power to one atom of sulphur (S).

The same general principle can be extended to all the other elements; or in other words, it can be shown how many atoms of each element are equivalent in forming compounds to one of hydrogen. Thus the equivalence, as it is called, of sodium is one, of calcium two, of gold three (also sometimes one), of tin four. In the compound $SbCl_5$ the equivalence of the antimony (Sb) is five, but in Sb_2O_3 only three.

Some complication comes in from the fact that it is found that the same substance has, within certain narrow limits, different equivalence in different compounds, as noted above of gold and antimony; thus, too, the chemist knows one compound FeO, another Fe_2O_3, and a third FeO_2. A good deal more attention must be given to the matter before it can be thoroughly understood, and for this the student must have a good course in chemistry, including not only the study of some standard book, but also practical work with a good teacher in the laboratory. But the explanations given should suffice to make it pretty clear, first, as to what the elements are; second, what is meant by their atomic weights; and third, the significance of their combining power, or equivalence. Some further explanations are needed as to chemical compounds.

The distinction between a *chemical compound* and a simple *mixture* of two elements is well illustrated by the air we breathe. The chemist finds by analysis that it is nearly constant in composition, containing essentially in one hundred parts 76.8 by weight of nitrogen* and 23.2 of oxygen. A little water vapor is also present, still less carbon dioxide.

Is the air a chemical compound? The answer is given at once that it is *not,* for the simple reason (and there are others equally conclusive) that the ratio of 76.8 to 23.2 is not that of the atomic weights of the two elements present, namely 14 : 16, nor of any simple multiples of these.

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* In this approximately one per cent has been shown to be the new element argon, which in many characters is closely related to nitrogen.

There are indeed several compounds of nitrogen and oxygen know to the chemist, namely,

$$N_2O, \qquad N_2O_3, \qquad N_2O_5;$$

but if they are analyzed, the relative amounts by weight of nitrogen and oxygen are found to be in the ratio of

$$\begin{array}{ccc} 2 \times 14 : 16 & 2 \times 14 : 3 \times 16 & 2 \times 14 : 5 \times 16 \\ \text{or } 28 : 16 & 28 : 48 & 28 : 80 \end{array}$$

One further point must be mentioned in regard to the compounds taken for illustration:

Sodium chloride, $NaCl$.
Calcium chloride, $CaCl_2$.
Gold chloride, $AuCl_3$.
Tin chloride, $SnCl_4$.

The first element in these and similar formulas is a *metal* and the second a *non-metal;* the first is said to be the positive element, the second is the negative element. Why the terms positive and negative are introduced is known to the student of electricity, for he has learned that in the decomposition of a compound by the electrical current—a very powerful means, often accomplishing the result when other methods fail—one element always goes to the positive pole or electrode, the other to the negative; the former is hence called the negative element, its atoms being attracted by the oppositely electrified positive electrode, and the second the positive, since its atoms are attracted by the negative electrode. Corresponding to this the metals are positive in nearly all their compounds, while the nonmetals are negative, and further the semi-metals are sometimes positive, sometimes negative. Remember that the positive element is always written first; this will be clear from the examples given above, and in the following:

FeO, FeS, PbO, PbS, etc.

Again, in As_2O_3 and As_2S_3 arsenic is positive, but in $FeAs_2$ and $CoAs_3$ arsenic is negative. Similarly among the metals there are some which in compounds with certain elements (as oxygen, sulphur) are always positive, while when combined with certain other metals they may be negative.

The names given to the different chemical compounds are in most cases easy to learn and understand. In the description of minerals, in the pages that follow, both the chemical names and the formulas are given so as to familiarize the student with each method.

When there are two or more compounds of the same elements, the name is usually such as to distinguish between them. Thus PbO and PbO_2 may each be called oxide of lead or lead oxide, but the first is properly *lead monoxide*[*] or *lead protoxide*, and the second *lead dioxide*.

The following are other examples:

FeO, iron protoxide, or ferrous[†] oxide.
Fe_2O_3, iron sesquioxide,[‡] or ferric oxide.

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[*] *Monoxide* means an oxide containing one atom (from μόνος. single) of oxygen; *dioxide* one containing two atoms (from δίς, twice); *protoxide* means the first oxide (πρῶτος, first) because the first or lowest of the oxides of the given metal in amount of oxygen present; the highest oxide is sometimes called *peroxide*.

[†] The terminations *-ous* and *-ic* are frequently used for the lower and higher oxides respectively.

[‡] *Sesquioxide* means a one-and-half oxide, because the ratio of oxygen to metal is $1\frac{1}{2} : 1$ or $3 : 2$.

FeS_2, iron disulphide.
Sb_2S_3, antimony trisulphide.
$SnCl_4$, tin tetrachloride.

The following are a few special names with which it is desirable to be familiar:

Na_2O, soda, instead of sodium oxide.
K_2O, potash, instead of potassium oxide.
CaO, lime, instead of calcium oxide.
MgO, magnesia, instead of magnesium oxide.
BaO, baryta, instead of barium oxide.
Al_2O_3, alumina, instead of aluminium trioxide.
SiO_2, silica, instead of silicon dioxide.

A few others might be added to this list.

It will be helpful to note briefly what are the common kinds of compounds found among minerals, so that the statement of the chemical composition and formula, given under the description of each species, may have a definite meaning. There are three fundamental divisions:

I. NATIVE ELEMENTS.—This is the simplest case of all, that of the elements, a few of which occur in nature and are hence called native elements, as *native gold, native sulphur,* etc.

II. SIMPLE COMPOUNDS, usually of two elements; there are four prominent classes.

(1) *Sulphides,* compounds of a metal with sulphur, as:

Galena, lead sulphide, PbS.
Sphalerite, zinc sulphide, ZnS.
Pyrite, iron disulphide, FeS_2.
Stibnite, antimony trisulphide, Sb_2S_3.

Similar to the sulphides and closely related to them are the rare tellurides, arsenides, antimonides, etc., as:

Altaite,* lead telluride, $PbTe$.
Niccolite, nickel arsenide, $NiAs$.
Breithauptite, nickel antimonide, $NiSb$.

(2) *Chlorides*, compounds with chlorine, as:
Halite (rock salt), sodium chloride, $NaCl$.
Cerargyrite, silver chloride, $AgCl$.

Similarly the rare bromides and iodides are compounds with bromine and with iodine, as:

Bromyrite, silver bromide, $AgBr$.
Iodyrite, silver iodide, AgI.

(3) *Fluorides*, compounds with fluorine, as:
Fluorite, calcium fluoride, CaF_2.

(4) *Oxides*, compounds with oxygen, as:
Cuprite, cuprous oxide, Cu_2O.
Zincite, zinc oxide, ZnO.
Hematite, iron sesquioxide (or ferric oxide), Fe_2O_3.
Cassiterite, tin dioxide, SnO_2.

The examples given under some of these heads, as the sulphides and oxides, illustrate the important point already spoken of: that there may be more than one kind of compound, varying in the number of atoms present, for example of oxygen, as Cu_2O, ZnO, Fe_2O_3, SnO_2. Even with the same metal two or more compounds are often known, though not always occurring in nature. Thus, besides cuprite,

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* Some rare minerals, not elsewhere mentioned, are for the sake of completeness included in this list.

Cu_2O, there is also a mineral called tenorite whose composition is CuO; also the chemist knows FeO, iron protoxide (or ferrous oxide), while Fe_2O_3, iron sesquioxide (or ferric oxide), is the common mineral hematite. Further, there is magnetite, whose percentage composition is expressed by the formula Fe_3O_4, also written $FeO.Fe_2O_3$; in this last case the chemist's view of the composition is a little too complex to be explained here. This, however, only illustrates again the limitation to which the beginner is subject, since he cannot expect to master all the relations of a large and difficult subject without much hard study. A little knowledge, however, is useful if it does not make the one who possesses it imagine that he has a deeper understanding of nature's laws than he really possesses.

There may be also, under each of these heads, compounds containing more than one metal, or, on the other hand, more than one negative element, as arsenopyrite, $FeAsS$, which is equivalent to $FeAs_2.FeS_2$. Another simple example is cryolite, Na_3AlF_6, which is equivalent to $3NaF.AlF_3$.

We may provisionally include here a series of rather rare compounds among minerals, of which class, though numerous, only a very few are alluded to in this book. The best example is tetrahedrite, whose formula is $Cu_8Sb_2S_7$, which we may write as if made up of two sulphides, thus: $4Cu_2S.Sb_2S_3$. Pyrargyrite, Ag_3SbS_3 or $3Ag_2S.Sb_2S_3$, is another example. Strictly, these compounds are regarded by the chemist as similar to those of the class now to be mentioned called Salts, but containing sulphur in place of oxygen.

III. COMPLEX COMPOUNDS, called SALTS.—These complex compounds may be referred back in each case to some *acid*, of which the given compound is said to be a *salt*. In these also the metal, usually written first, is the positive part, the remainder the negative. in the electro-chemical sense in which the terms were used on page 107. The metal is thought of as taking the place of the hydrogen atom or atoms in the formula of the given acid. The principal classes are:

Carbonates, salts of carbonic acid, H_2CO_3, in which some metal, as calcium, lead, etc., takes the place of the two hydrogen atoms, as:

Calcite, calcium carbonate, $CaCO_3$.
Dolomite, $CaMg(CO_3)_2$ or $CaCO_3.MgCO_3$.
Cerussite, lead carbonate, $PbCO_3$.

Sulphates, salts of sulphuric acid, H_2SO_4, and similarly chromates, tungstates, molybdates, as:

Barite, barium sulphate, $BaSO_4$.
Anglesite, lead sulphate, $PbSO_4$.
Crocoite, lead chromate, $PbCrO_4$.
Scheelite, calcium tungstate, $CaWO_4$.
Wulfenite, lead molybdate, $PbMoO_4$.

Phosphates, mostly salts of the phosphoric acid H_3PO_4. Closely related are the arsenates and vanadates; less closely the rarer antimonates and nitrates. The mineral triphylite (not common) has the composition $LiFePO_4$ or $Li_3PO_4.Fe_3(PO_4)_2$; the rare mineral xenotime has the composition yttrium phosphate, YPO_4; pucherite, also very rare, is bismuth vanadate, $BiVO_4$. Other examples are afforded by the common minerals: apatite, essentially calcium phosphate, $Ca_3P_2O_8$ or $Ca_3(PO_4)_2$; pyromorphite, lead phosphate, $Pb_3P_2O_8$; mimetite, lead arsenate, $Pb_3As_2O_8$; vanadinite, lead vanadate, $Pb_3V_2O_8$. In all of these, however, the composition is in fact a little more complex than these simple formulas would suggest, since chlorine (and, with apatite, fluorine) enters in small amounts; this is again a point which it will not be attempted to explain here.

Less common than the preceding classes are the *Tantalates* and *Niobates* (columbates), as:

Tantalite, iron tantalate, $FeTa_2O_6$.
Columbite, iron niobate, $FeCb_2O_6$.

There is also a group of *Borates*, mostly very rare minerals.

A very large and important but complex group is that of the *Silicates*. These are salts of several kinds of silicic acids, the commonest of which are metasilicic acid, H_2SiO_3, and orthosilicic acid, H_4SiO_4, as:

Rhodonite, manganese metasilicate,* $MnSiO_3$.
Willemite, zinc orthosilicate, Zn_2SiO_4.

Other silicates are:

Pyroxene (diopside), $CaMg(SiO_3)_2$ or $CaMgSi_2O_6$.
Beryl, $Be_3Al_2(SiO_3)_6$ or $Be_3Al_2Si_6O_{18}$.

These are metasilicates, while the two following are orthosilicates:

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* The designations *meta-* and *ortho-* are often omitted, and the compounds described simply as silicates.

Garnet (grossularite), $Ca_3Al_2(SiO_4)_3$ or $Ca_3Al_2Si_3O_{12}$.
Zircon, $ZrSiO_4$.

Also

Orthoclase, $KAlSi_3O_8$.
Albite, $NaAlSi_3O_8$.

And again

Andalusite, Al_2SiO_5.

Besides the two types first mentioned, there are others, as those represented by orthoclase (or albite) and by andalusite, and further still others, many of them very complex and in some cases not clearly understood, notwithstanding all the study that has been given to the subject. All of these points require much more knowledge than can be demanded of a beginner in mineralogy.

As illustrated by the examples given, a silicate commonly contains more than one metal, perhaps four or five or even more. The same thing is also true of the compounds belonging under the other classes of salts, though they are not usually so complex as the silicates; with them also, in some cases, two of the negative elements may be present.

In this connection it is also important to understand that the relative amounts of the metals present may in a given case vary widely, as the amounts of calcium, iron, etc., in the different kinds of garnet. For example, besides pure calcium carbonate, $CaCO_3$ (calcite), and magnesium carbonate, $MgCO_3$ (magnesite), there are many intermediate compounds, to which the general name dolomite is given, containing more or less of the two metals, and for them the formula is then written $(Ca,Mg)CO_3$. For normal dolomite, however, in which one atom each of calcium and magnesium is present, the formula is written $CaMgC_2O_6$ or $CaMg(CO_3)_2$; the difference between these forms (with and without a comma) should be noted. So, too, the three compounds of lead mentioned under the head of Phosphates, namely, the minerals pyromorphite, mimetite, vanadinite, have many intermediate compounds containing in varying amount two of the negative elements phosphorus, arsenic, vanadium.

The formulas of these salts are often written as if separated into the corresponding simple oxygen compounds or oxides, as $CaO.CO_2$ instead of $CaCO_3$. The chemist does not, however, believe that the calcite molecule is made up of these two parts, only this method of writing is convenient because these are the parts readily obtained by analysis; in this particular case by simply heating the substance it gives off CO_2, and CaO is left behind.

So, too, we may write either

$CaMg(SiO_3)_2$ or $CaMgSi_2O_6$ or $CaO.MgO.2SiO_2$;
$Ca_3Al_2(SiO_4)_3$ or $Ca_3Al_2Si_3O_{12}$ or $3CaO.Al_2O_3.3SiO_2$;
$KAlSi_3O_8$ or $K_2O.Al_2O_3.6SiO_2$;
Al_2SiO_5 or $Al_2O_3.SiO_2$; and so on.

Hydrous Compounds.—Finally, there are also a large number of minerals which yield *water* when heated; sometimes this means only that the elements of water (hydrogen and oxygen) are present in the complex compound and they combine at the high temperature. This is true, for example, in talc.

In the majority of cases, however, the water is believed to be present as *water of crystallization,* as if water molecules were present with the other molecules when the compound was crystallized out from the solution. These species are called *hydrous compounds,* and they as a rule give off water at a comparatively low temperature. Thus gypsum is hydrous calcium sulphate, and its composition is expressed by the formula

$$CaSO_4 + 2H_2O.$$

Other examples of hydrous minerals are the zeolites, among silicates, mentioned near the end of the chapter on the Description of Species. Still another important class are the *hydrates,* or hydrated oxides—that is, oxides which yield water when heated. A good example is brucite, whose formula is written $Mg(OH)_2$ or $MgO.H_2O$.

Percentage Composition.—It was shown on p. 104 that, from the proportion by weight of the different elements obtained by the analysis of the chemist, the chemical formula could be deduced by the aid of the table of atomic weights. Conversely, if the formula is given, the *percentage composition,* or the amount by weight of each element or group of elements present in the compound in one hundred parts, can be easily calculated. Thus sodium chloride, or common salt, has the formula NaCl, as has been shown, and hence, taking the atomic weights of sodium and chlorine, the relation of the weight of sodium to that of chlorine is as the numbers 23 : 35.5. Now adding together 23 and 35.5 we obtain 58.5, which is called the weight of the molecule, or molecular weight. Further, by the rule of three, if 58.5

parts of the compound contain 23 parts of sodium, 100 will contain 39.32 parts:

$$58.5 : 23 \quad = 100 : 39.32, \text{ or } \frac{23 \times 100}{58.5} = 39.32;$$

and

$$58.5 : 35.5 = 100 : 60.68, \text{ or } \frac{35.5 \times 100}{58.5} = 60.68.$$

The percentage composition of sodium chloride is, therefore:

Na	39.32
Cl	60.68
	100.00

Again, the formula of stibnite, Sb_2S_3, means that two atoms of antimony (Sb) unite with three of sulphur (S). But the atomic weights of antimony and sulphur are 120 and 32 respectively. The molecular weight is, therefore, equal to

$$2 \times 120 + 3 \times 32 = 240 + 96 = 336.$$

Hence in 336 parts, 240 are antimony and 96 sulphur, and to find the amount of each in one hundred parts we have the proportions

$$336 : 240 = 100 : 71.43, \text{ or } \frac{240 \times 100}{336} = 71.43.$$

$$336 : \ 96 = 100 : 28.57, \text{ or } \frac{96 \times 100}{336} = 28.57.$$

The percentage composition is, therefore:

Sb	71.43
S	28.57
	100.00

Again, the formula of one kind of garnet is $Ca_3Al_2Si_3O_{12}$ or, as it may be written, $3CaO.Al_2O_3.3SiO_2$. Taking the second form and finding the atomic weights for each element from the table, adding them together for each group of atoms and multiplying by the factor given, we have:

$$\begin{aligned} 3\mathrm{CaO} &= 3(40 + 16) = 3 \times 56 &&= 168 \\ \mathrm{Al_2O_3} &= 2 \times 27 + 3 \times 16 = 54 + 48 &&= 102 \\ 3\mathrm{SiO_2} &= 3(28 + 2 \times 16) = 3 \times 60 &&= \underline{180} \\ & && \ 450 \end{aligned}$$

Hence again, by the rule of proportions:

$$\begin{aligned} 450 : 168 &= 100 : 37.33 \\ 450 : 102 &= 100 : 22.67 \\ 450 : 180 &= 100 : 40.00 \end{aligned}$$

The percentage composition is, therefore:

Lime, CaO	37.33
Alumina, Al_2O_3	22.67
Silica, SiO_2	40.00
	100.00

If desired it would have been as easy to deduce the amounts of the elements Ca, Al, Si, O present, but, as stated on p. 115, it is more convenient to use the oxides instead.

CLASSIFICATION.

There are various methods of classification that may be adopted for minerals. The strictly scientific way is to arrange similar compounds together, that is, first, the native elements; then the sulphides, the oxides, the carbonates, and so on. These are further classified by the relationships which a study of the elements and of the crystalline forms of their compounds makes known.

For example, the following minerals being all carbonates are, on a strictly scientific method, placed in the same general division:

Calcite, calcium carbonate, $CaCO_3$.
Dolomite, calcium-magnesium carbonate, $CaMg(CO_3)_2$.
Magnesite, magnesium carbonate, $MgCO_3$.
Siderite, iron carbonate, $FeCO_3$.
Rhodochrosite, manganese carbonate, $MnCO_3$.
Smithsonite, zinc carbonate, $ZnCO_3$.

Further, they are all placed side by side in the same group, called the Calcite group, because they have the same general crystalline form and very nearly the same angles, e.g., all show rhombohedral cleavage with the angle varying from 105° to 107°. This is called, therefore, an *isomorphous group*, having like form * and analogous composition.

Another series of minerals, also in the same division of carbonates, form a second isomorphous group, the Aragonite group:

Aragonite, calcium carbonate, $CaCO_3$.
Witherite, barium carbonate, $BaCO_3$.
Strontianite, strontium carbonate, $SrCO_3$.
Cerussite, lead carbonate, $PbCO_3$.

A third case is the Barite group of sulphates:

Barite, barium sulphate, $BaSO_4$.
Celestite, strontium sulphate, $SrSO_4$.
Anglesite, lead sulphate, $PbSO_4$.

Also, a little less closely related,

Anhydrite, calcium sulphate, $CaSO_4$.

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* Isomorphous is from ἴσος, *like*, and μορφή, *form*.

The Galena group (galena, argentite, etc.), the Apatite group (p. 113), the Feldspar group, the Mica group, are other examples. These and many besides are described in an advanced work on mineralogy.

Another method of classification is to place together the different compounds of each metal, as all the compounds of iron, all those of silver, and so on. Still another way would be to put the metallic ores together, the gems, and so on. Of these and still other different methods, the most satisfactory for us is the second, as further explained on a later page (p. 158 *et seq.*).

It will be noticed, in the cases of the two groups taken for illustration, that the same composition, calcium carbonate, $CaCO_3$, belongs to two minerals, calcite and aragonite. These are regarded as distinct species because they have a different crystalline form and different physical characters, e.g., specific gravity. What is true of this chemical compound is true of a number of others. Among minerals, such compounds are said to be *dimorphous* or to have two forms.

CHAPTER VI.

THE USE OF THE BLOWPIPE.

1. General Description of Apparatus.

The chemist in the laboratory, as has been already explained, can subject a mineral specimen to a process of analysis, and in this way discover, first, what simple substances or elements it contains, and, second, in what proportion by weight they are present; in other words, he can analyze it. This has been done many times in the case of all the minerals we know, and the result has been to show what the composition of each species is, and by what formula this can be expressed.

It is obvious that this method of complete analysis is the only satisfactory way to gain a complete knowledge of the chemical nature of a given mineral. But the work of the chemist is slow and laborious, and it is often important to be able to learn something about the composition of a mineral more quickly and by an easier method. This can be done by the blowpipe, supplemented by some simple chemical tests; and any one who is supplied with a few tools, and who has the patience to learn to use them, can accomplish it. The results of this blowpipe analysis, taken in connection with the study of the physical characters of a given specimen, almost always suffice to enable a mineralogist who has a fair amount of knowledge and experience to determine what it really is, even if at first it was entirely unknown.

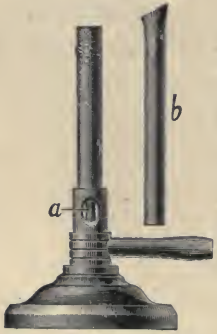
The following list includes the articles that are most essential for this work:

1. Lamp.
2. Blowpipe.
3. Platinum-pointed forceps.
4. Charcoal.
5. Platinum wire.
6. Glass tubes.

Also (7) a few chemical reagents as explained beyond. After some words of explanation about each of these, several other appliances which it is also convenient to have will be mentioned.

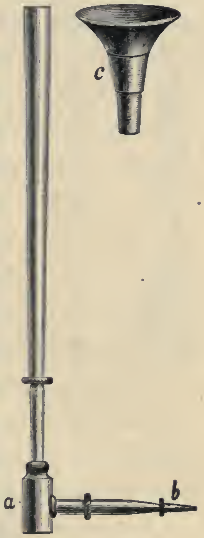
1. *Lamp.*—The most convenient form of lamp is a Bunsen gas-burner (Fig. 149); it is provided with a special jet (*b* in the figure). This burner can be connected with any ordinary gas-jet by a rubber tube, so as to be placed on the table for use. In the Bunsen burner proper, that is, when the jet *b* is not inserted, the gas mingles in the tube with the air which enters at *a*, and they together burn at the top in a very hot flame, but one which gives very little light and which deposits no soot upon a surface of cold glass or porcelain. This flame is used by the chemist in the laboratory, and also by the mineralogist in heating glass tubes as described beyond.

149.



Instead of the Bunsen burner an alcohol lamp may be employed, and in fact was long used by the early chemists; alcohol, however, is a very inflammable substance, so that its use requires much care. One precaution also must be observed with the Bunsen burner: it is best *not* to turn the flame down low (unless the end of the tube is covered with a cap of wire gauze), for if this is done the flame is liable to "snap down," that is, the gas may ignite within the tube just above *a* (Fig. 149). It then burns with a feeble yellowish flame, yielding a disagreeable odor, and the tube becomes immediately very hot. This is *dangerous*, not only because a severe burn may result from touching the tube, but, still more, because if left a few moments the rubber tube may be melted, the gas ignite from it, and a serious fire be caused. Hence it is better never to go out of the room and leave a Bunsen flame burning even for a few minutes. In a laboratory where there is a slate table this precaution is not so important.

150.

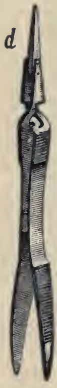


When the jet *b* is inserted in the tube of the Bunsen burner the air-supply from the openings below is cut off and the gas now burns at the top with the usual yellow flame, here flattened by the shape of the jet; the convenient flame for ordinary use is about one and a half inches in height. This is the flame to be used with the blowpipe. Instead of this gas-flame a good stearine candle will answer the purpose sufficiently well, or an oil lamp with a suitable burner.

2. *Blowpipe.*—A common form of blowpipe is shown in

Fig. 150. It may be very simple and inexpensive, but should have an air-chamber, *a*, to collect the condensed moisture from the breath. A separate tip (*b*), either of brass or platinum, with a fine hole, is often used, but it is not absolutely necessary. The essential thing is that the hole, whether in the tip or the tube itself, should be large enough and not too large, and also that it should be round and true, so that a moderate pressure of air shall suffice to blow a clear blue flame (see Fig. 153). A trumpet-shaped mouthpiece (*c*) is usually furnished, but some prefer to dispense with it.

151.



3. *Forceps.*—A pair of steel forceps (Fig. 151) is needed, and it is desirable that they should be nickel-plated to prevent rusting. One end has platinum points at *d*, self-closing by a spring, so that the piece of mineral to be heated, placed between them, is firmly supported. At the other end are ordinary forceps for picking up small fragments; this end should never be inserted in the flame. A caution in regard to the use of the platinum points is given on p. 130, for, though infusible, they can be easily injured.

4. *Charcoal.*—Several pieces of charcoal are needed. These are most conveniently rectangular in shape (see Fig. 156) and about four inches long, an inch wide, and three fourths of an inch thick. The charcoal must burn without snapping and must leave very little white ash. It is so difficult to obtain really good charcoal that it is well worth while to purchase a few pieces expressly prepared for the purpose, and with care one piece will last for

many experiments, the surface being rubbed clean, as by a file or knife, after each use.

5. *Platinum Wire.*—A few inches of platinum wire, of the size designated No. 27, usually sold for this purpose, are needed; directions for its use are given on a later page. In addition to the wire, a small piece of platinum foil is sometimes useful.

6. *Glass Tubes.*—Some tubes of rather hard glass are required; it is convenient to have two sizes, with bores of one sixth and one quarter of an inch, but one will suffice. The larger size can be cut into pieces about five inches in length; the tube will break easily if a single scratch is first made with the edge of a three-cornered file. These tubes are to be used as *open tubes*, as explained later. Again, pieces a little longer, say six inches, and of the size with the smaller bore, may be taken and held with the middle point in the hot part of the Bunsen flame. When the glass is soft, draw the two ends apart by a quick motion (without twisting), and then heat each long tapering end in the flame and pinch it off short while hot, using for this the steel end of the forceps. In this way two *closed tubes* will be made from each piece; a considerable number should be made and kept in a closed box for use. A tube must be clean inside and out, and should not be used twice.

7. *Fluxes and other Chemical Reagents.*—The chemical reagents needed are the *fluxes* * borax (sodium tetraborate), soda (sodium carbonate), and salt of phosphorus, or microcosmic salt (phosphate of soda and ammonia). Each of

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* So called because they help in the melting or fusion of the substance under examination.

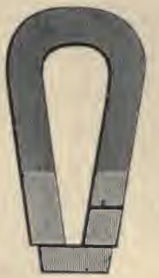
these may be kept in a round wooden pill-box, or in a small bottle with a glass stopper. A little potassium bisulphate, to be kept in a glass bottle, is occasionally needed. Small bottles of hydrochloric, nitric, and sulphuric acids are also useful, and one of a solution of cobalt nitrate; these bottles may conveniently have a glass dropping-tube with a bulb in the place of the ordinary glass stopper.

Test-paper is also required, cut up into small strips, both turmeric-paper and blue litmus-paper. The *yellow* turmeric-paper is turned *brown* by an alkali, such as soda, while the *blue* litmus-paper is turned *red* by an acid or acid fumes, as of sulphur dioxide in the open tube. Red litmus-paper turns blue with an alkali, but the turmeric-paper is better.

In addition to the above, the following articles will be found very convenient, though not all of them quite so essential:

A small hammer having a square face with sharp edges; also a steel anvil an inch or two long.

152.



A horseshoe magnet (Fig. 152), the place of which may be taken by a magnetized knife-blade.

A small agate mortar and pestle; also a steel diamond mortar (one in which the pestle fits tightly) in which a hard mineral can be pulverized without loss of the fragments.

A pair of cutting pliers.

A three-cornered file.

A few small watch-glasses are convenient; also several small dishes of glass or porcelain (smooth butter-plates are very good) to hold the fragments of the mineral under examination; several test-tubes; a porcelain dish, or casserole, in which a substance can be heated with acid. Also, if chemical tests proper are to be tried, a wash-bottle (for distilled water), a bottle of ammonia, and some filter-paper.

Before beginning to experiment it is best to put a thick sheet of cardboard, covered each time with a fresh piece of white paper, upon the table and place the lamp upon this. A slate or a sheet of plate glass is even better than the cardboard.

The student must remember also that the acids mentioned are powerfully corrosive in their action, staining and finally destroying any fabric, as clothes or the carpet, which they are allowed to touch.* Moreover, the fumes from the acids when hot are injurious; for any extended series of strictly chemical trials it is almost essential, therefore, to have some of the conveniences of a laboratory. Still another caution is needed: do not put away a piece of charcoal after use until it is quite certain that *no fire* lingers in it.

2. How to Use the Blowpipe.

The first thing in the use of the blowpipe is to learn to blow a hot, steady flame. Place the tip of the blowpipe close to or just within the flame as shown in Fig. 153, directing it slightly downward, and blow through the tube. The blast of air will direct the flame into a thin cone, and with a little practice a clear blue flame quite free from yellow will be the result. This flame is much hotter than the ordinary gas-flame, and when the blowpipe is in skillful hands it is hot enough to melt a fine platinum wire. The hottest part is just at the extremity of the blue flame (shaded in Fig. 153).

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* In case of accident the effect of the acid can often be neutralized by the prompt application of ammonia or carbonate of soda, which may afterward be washed out with a little water.

It seems difficult at first to blow a *continuous* steady flame, but it is really very easy. It is only necessary to continue slowly to breathe through the nose while the pressure of the cheeks upon the reservoir of air kept all the time in the mouth prolongs the blast. This pressure need not be great—not enough to tire the cheek-muscles sensibly except after a long time; if fatigue soon comes, it is because the student is unskillful or has a bad blowpipe.

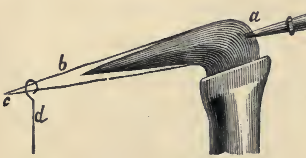
It is not wise, however, to give too much thought to the learning of the art of steady blowing; this will come quickly with practice. At the same time it will not do to be careless about the character of the flame; the student is ready to go on when he can take a thin sliver of orthoclase and without great difficulty melt the edges.

An important distinction must be made between the *reducing flame* and the *oxidizing flame*. The flame in general consists of two parts: the inner blue cone, and the outer almost invisible envelope extending far beyond. In the former the gas is only partly burned; there is a deficiency of oxygen, and a substance which at that temperature can part with its oxygen is *reduced*. Here the reducing effect is to rob of oxygen, as when oxide of nickel, NiO, is changed to metallic nickel (Ni); or iron sesquioxide (Fe_2O_3) is changed to iron protoxide (FeO).

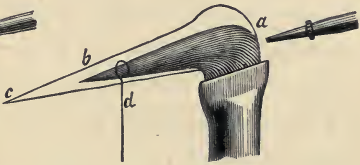
In the outer part of the flame, on the other hand, there is an excess of oxygen from the surrounding air, and the tendency is to give oxygen, or to *oxidize.* Here the lower oxide of manganese, MnO, is changed to the higher oxide, Mn_2O_3.

This distinction between the action of the two parts of the flame is very important in a certain class of experiments. The student must notice further that to blow a good strong oxidizing flame the tip of the blowpipe should be placed just inside the gas-flame, as indicated in Fig. 153; the flame is then free from any yellow, and the substance under experiment is to be held well beyond the end of the blue cone, at *d*.

153.



154.



For a good reducing flame, on the other hand, the tip should be a little outside of the gas-flame (Fig. 154), so that a little yellow follows the flame down, above the blue cone; the substance is held at *d*, *within* the blue cone, and best more or less surrounded by the yellow flame. The experiment described on p. 138 with manganese will show the learner with what success he is following the directions here given.

In the following pages the different methods of examination with the aid of the blowpipe are described fully. The student should take them up in order, going through as many as possible of the trials with the minerals suggested and endeavoring to obtain the results described as closely as he can. It is essential that the material used for the experiments should be pure.

3. Examination in the Forceps.

A small fragment of a mineral, held in the platinum points of the forceps, may be tested to see whether it can be melted, and, if so, whether easily or with difficulty. At the same time it may be observed that the mineral imparts a color to the flame which will give information as to its composition, while other phenomena, as detailed below, may also be noted.

And here a few important suggestions must be made. It is very necessary to remember that while platinum cannot be injured by the heat of the blowpipe flame, nor attacked by the ordinary acids used by the chemist, it may yet be easily injured. A mineral containing antimony or arsenic, if fused in the forceps, may destroy the platinum points, for these metals form a very fusible alloy with platinum. Hence it is desirable to try minerals about which there is question—especially a mineral with metallic luster—in the closed tube or on charcoal first, and if there are fumes given off, caution is needed.

In any case it is a good rule never to let the fused part of the mineral fragment come in contact with the platinum; for it may adhere to the points in an inconvenient way, even if not capable of doing any permanent harm, and thus much time be wasted in cleaning them.

Take now a little sliver, if possible with a thin edge, of a piece of barite or heavy spar; place it between the platinum points, letting the edge project well beyond them; blow a clean blue flame with the blowpipe, and just in front of this (in the oxidizing flame, see Fig. 153) insert the mineral. It will be seen to melt rather easily to a white opaque glass; at the same time the flame beyond will be streaked with a pale yellowish green, which is characteristic of the element barium. Further, if the fused end, after it has cooled, be placed upon a piece of moistened turmeric-paper, it will be seen to turn it brown, showing the presence of an alkaline earth.

If a piece of a barite *crystal* is taken, it is very likely to break violently into fragments when the flame is thrown upon it. This is called *decrepitation* and is not uncommon, especially with crystallized minerals. It can often be prevented by heating the fragment quite *slowly* at first, but in some cases it is necessary to begin by reducing the mineral to a fine powder, then mix it with a drop of water in the agate mortar, and finally support the thick paste so formed on a loop at the end of the platinum wire.

Scale of Fusibility.—The method of experiment described gives in the first place an approximate determination of the melting-point or degree of fusibility. The following scale is used to define the fusibility of the different minerals:

1. *Stibnite* (must be heated on charcoal): fusible in the ordinary gas-flame even in large fragments.

2. *Natrolite:* fusible in fine needles in the ordinary gas-flame, or in larger fragments in the blowpipe-flame.

3. *Almandite,* or iron-alumina garnet: fusible to a globule without difficulty with the blowpipe, if in quite thin splinters.

4. *Actinolite:* fusible to a globule in thin splinters.

5. *Orthoclase:* thin edges can be rounded without great difficulty.

6. *Bronzite:* fusible with difficulty on the finest edges.

The following list gives the names of some minerals, most of them common, with the degree of fusibility of each according to this scale. It is repeated here that for minerals with metallic luster the trial should be in charcoal.

Stibnite, galena	1.
Cryolite, apophyllite, pyromorphite	1.5
Amblygonite, witherite, prehnite, arsenopyrite	2.
Rhodonite, analcite	2.5
Gypsum, barite, celestite, fluorite, epidote	3.
Oligoclase	3.5
Albite	4.
Apatite, hematite, magnetite	5.
Bronzite	6.

Infusible: quartz, calcite, topaz, sphalerite, graphite.

It may be interesting here to add the temperatures (in degrees Centigrade) at which the prominent metals fuse, that is, pass from the solid to the liquid state:

Mercury	—39°	Antimony	450°
		Silver	1020°
Tin	230°	Copper	1090°
Bismuth	320°	Gold	1100°
Lead	330°	Iron	1500°
Zinc	420°	Platinum	2000°

The student must be warned that the method of expressing the fusibility of a mineral, by referring it to the scale given, is not exact. The results obtained in different cases will depend upon the size and shape of the fragment taken, the conductivity for heat, also obviously upon the skill of the experimenter.

Flame coloration.—Besides the fusibility, this experiment with a fragment of barite in the forceps serves to prove the presence of barium by the color given to the flame. It is found that a considerable number of substances are characterized in the same way, hence the flame coloration becomes a simple and important means of qualitative blowpipe chemical analysis.

Color of the Flame.—The following is a list of the colors likely to be observed and the substances to which they are due:

RED	*Carmine-red*	Lithium.
	Purple-red	Strontium.
	Yellowish red	Calcium.
YELLOW		Sodium.
GREEN.	*Yellowish green*	Barium.
	Siskine-green	Boron.
	Emerald-green	Copper.
	Bluish green	Phosphoric acid and phosphates.
BLUE	*Greenish blue*	Antimony.
	Whitish blue	Arsenic.
	Azure-blue	Copper chloride.
	Violet	Potassium.

It may be noted here that the blue flame of copper chloride is sometimes used as a test for chlorine. For example, if powdered pyromorphite be mixed with a little cuprite, also in the form of powder, and the mixture be fused together upon charcoal, a blue flame will be obtained for a moment, indicating that the pyromorphite contains some chlorine.

A bluish-green flame is also given by tellurium; yellow-green by molybdenum; whitish green by metallic zinc. *Blue* flames are also given by lead (on charcoal) and by selenium.

The color characteristic of a given substance is often masked by another; thus the green due to the boron in borax is concealed by the stronger yellow of the soda, but may be seen clearly if a drop of sulphuric acid is placed on the substance before heating. Similarly, the same treatment shows the bluish green of the phosphorus in salt of phosphorus, which also contains soda. Further, a difficultly fusible, or infusible, mineral is often not sufficiently decomposed by simple heat to show the flame-color, and hence a more complex method is called for; thus a fragment of apatite, first moistened by sulphuric acid, gives in the forceps the green for phosphoric acid. Again, orthoclase may be mixed with an equal bulk of powdered gypsum, a paste made with a little water, and this fused on a clean platinum wire, when the violet flame of potassium becomes visible, unless indeed masked by soda, in which case a piece of blue glass will extinguish the yellow and allow the violet to be seen. Further, the test for boron applicable to the silicate tourmaline is given under the description of that species.

In the case of carbonates, as calcite, strontianite, etc., a drop of hydrochloric acid will result in the formation of a little chloride (of calcium, strontium, etc.), which colors the flame more intensely. It is obvious that great care is needed to keep the platinum points of the forceps, or the wire, perfectly clean. A wire which has been handled or moistened with saliva will always give a yellow (sodium) flame.

At the same time that he tests the fusibility and flame color of a mineral, the student must keep his eyes open to note other attendant phenomena. Some of the points he may observe are the following:

The fragment, instead of fusing quietly, may

(*a*) *Swell up,* throw out little globules or curling processes, as stilbite.

(*b*) *Intumesce;* that is, bubble up and then fuse, as scapolite and most zeolites.

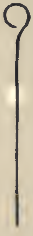
(*c*) *Exfoliate;* that is, swell up and open out in leaves, as apophyllite and, even more, vermiculite.

(*d*) *Glow brightly,* without melting, as calcite.

Also the fragment after being heated must be examined to see whether, if fused, the glass is clear, full of bubbles (then often called *blebby,* or *vesicular*), or even black; whether it has changed color, even if not fused; whether it is magnetic (due to iron); whether, if placed on moistened turmeric-paper, it turns it brown, as is true of an alkali, as soda, or an alkaline earth, as lime or baryta.

Finally, a few infusible substances turn *blue* when, after being heated, they are moistened with a drop of cobalt solution and again heated; this is true of cyanite, kaolin, and other infusible minerals containing *alumina.* Calamine (zinc silicate) also turns blue under these circumstances. A blue obtained with fusible minerals treated in this way may be simply due to the cobalt (see p. 138). Further, some minerals containing *magnesia,* as the hydrate brucite, with similar treatment turn a pale *pink.*

4. Use of the Platinum Wire.



155.

Wind the platinum wire about a small piece of card,* leaving some three inches free; then bend the end partially around so as to make an open loop nearly as big as a very small pea (Fig. 155), it is now ready for use. Heat this in the blowpipe-flame and dip it into the borax; some will adhere, which is then to be fused together to a colorless glass. Then add a little more, and repeat the operation until the bead is clear and round and fills the loop entirely; it must not be too big or it will fall off the wire.

Now take a little cuprite or malachite in very fine fragments, heat the bead and bring it in contact with one of them; it should adhere, and when heated again in the flame—it should now be held in the oxidizing flame—it will slowly dissolve and disappear (note the emerald-green flame of the copper). Now examine the bead, and if the quantity of the copper mineral was very small it will be found to be clear green while hot, and blue when cold. If a larger amount was taken or is now added, and the bead again heated, it may remain green on cooling, or even be so deeply colored as to appear black and opaque. In the last case the color may often be seen if the bead is heated hot and quickly flattened out by the pressure of the agate pestle. In every case it is best to commence with a very minute portion and then add more, rather than to take so much that the bead is black. If too much has been taken, it is best to shake off the bead from the wire by a sudden motion when hot, or break it when cold, and commence again.

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* Instead of this, the wire may perhaps better be cut into short pieces (say three inches or less in length), and each fused into a glass tube drawn out as described on p. 125.

Suppose now that the bead is deep green and contains a relatively large amount of copper, or is *saturated,* as it is called. Hold it in the *reducing flame* (see Fig. 154), and heat again. Now the oxygen needed to burn the gas will be taken in part from the oxide of copper (CuO) in the bead and part of it will be changed or reduced to the lower oxide of copper, Cu_2O, which will show red and opaque when the bead is cold.

After having obtained this red opaque bead it will be good practice to heat it again carefully in the oxidizing flame until the bead is once more perfectly clear and green in color. The color of the borax bead thus is a test which can prove the presence of copper, and similarly also of a number of the other metals.

The following is a list of the common metallic oxides and the colored beads that they yield. The distinction between the oxidizing flame (O. F.), which is to be used first, and the reducing flame (R. F.) is to be carefully observed. Thus nickel gives a violet bead in the O. F. from the oxide NiO, while in the R. F. this becomes gray and muddy from metallic nickel. Also manganese gives in the O. F. a deep wine-red, from the presence of the sesquioxide (Mn_2O_3), and in the R. F. it becomes colorless, the protoxide (MnO) being formed.

Colors of the Borax Beads.

(1) OXIDIZING FLAME (O. F.).

Red, red-brown, and brown.	Chromium (Cr_2O_3) when hot; yellowish green when cold.
	Manganese (Mn_2O_3) amethystine-red; violet when hot.
	Iron (Fe_2O_3) when hot; yellow when cold, when saturated.
	Nickel (NiO) red-brown to brown when cold; violet when hot.
	Uranium (UO_3) when hot; yellow on cooling.
Green.	Copper (CuO) when hot; blue when cold, or bluish green if highly saturated.
	Chromium (Cr_2O_3) when cold; yellow to red, hot.
Yellow.	Iron (Fe_2O_3) when hot; pale yellow or colorless when cold (if saturated, red-brown and yellow).
	Uranium when hot and feebly saturated; paler on cooling.
	Chromium (Cr_2O_3) when hot and feebly saturated; yellowish green when cold.
Blue.	Cobalt (CoO) hot and cold.
	Copper (CuO) when cold; green when hot. If highly saturated, bluish green when cold.
Violet.	Nickel (NiO) hot; red-brown to brown cold.
	Manganese (Mn_2O_3) hot; violet-red cold.

(2) REDUCING FLAME (R. F.).

Colorless.	Manganese (MnO), or with a faint rose-color.
Red.	Copper (Cu_2O) opaque.
Green.	Iron (FeO) bottle-green.
	Chromium (Cr_2O_3) emerald-green.
	Uranium (U_3O_8); yellowish green if saturated
Blue.	Cobalt (CoO).
Gray or turbid.	Nickel (Ni).

It may be added that many of the common metals, both O. F. and R. F., as silver, zinc, lead, etc., further silica, etc., give colorless beads.

To expel the arsenic, antimony, or sulphur, the process of *roasting* is performed. This consists in heating the powdered substance on charcoal cautiously, so as not to fuse it, first in the O. F., then in the R. F., and repeating this a number of times patiently. The mineral should still be in the state of a powder at the end.

It must be noticed that when two metals are present together, the color of one may not be seen; thus, if iron, nickel, and cobalt are all in the substance under examination, the colors are observed in the order given, if each metal in turn is oxidized off by skillful treatment on charcoal with successive portions of borax.

Salt of phosphorus is used especially for some of the rarer elements; in general the results are nearly the same as with borax. The following may be noted:

Titanium (TiO_2), in O. F. yellow hot, colorless cold; in R. F. yellow hot, fading out to a delicate violet.

Chromium (Cr_2O_3), in O. F. red when hot, dirty green on cooling, fine green when cold; in R. F. nearly the same.

Uranium, in O. F. yellow when hot, yellowish green when cold; in R. F. yellowish green when hot, and green cold.

Vanadium, in O. F. dark yellow when hot, paler on cooling; in R. F. brownish red when hot, chrome-green on cooling.

Molybdenum, in O. F. yellowish green hot, paler on cooling; in R. F. dirty green hot, green when cold.

Niobium (*columbium*), in O. F. yellow when hot if slightly saturated, colorless on cooling; in R. F. dirty blue when hot, and blue cold if highly saturated.

It is also to be noted that silica (as quartz) or a silicate does not dissolve entirely in salt of phosphorus, as in borax, but the metallic oxides dissolve out and leave a skeleton of silica floating around in the bead.

The making of the salt-of-phosphorus bead on the wire calls for a little skill. The salt contains considerable water of crystallization, and when first heated it melts in this and becomes so fluid as to fall from the wire; hence small quantities should be taken and fused till the boiling has ceased before more is added; also, and this is particularly important, during the preliminary process hold the bead just *over* the flame, not in it, then the vapors expelled will support the fluid bead and keep it from falling.

Soda is particularly useful on charcoal in reducing the metallic compounds as described below. With manganese in the oxidizing flame soda gives a fine bluish-green but opaque bead. The soda beads in general are opaque, but with silica a clear glass may be obtained.

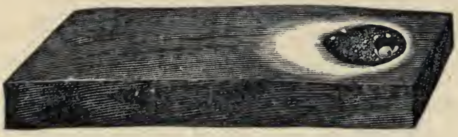
5. USE OF THE CHARCOAL.

A piece of charcoal such as has been described on p. 124 is very useful in the chemical examination of minerals with the blowpipe. It forms a support, in the first place, upon which a deposit may be formed of the volatile compound formed by heating the substance. Besides this the glowing carbon has what has been called (p. 128) a powerful reducing effect, that is, it takes oxygen (or other elements) away, and sometimes without other means this suffices to produce the metal from its compound. Thus cuprite (Cu_2O), or red oxide of copper, is reduced to metallic copper by heating on charcoal; similarly chalcocite (Cu_2S) may be treated with the same result; cerargyrite ($AgCl$) yields metallic silver.

Instead of charcoal a plate of plaster of Paris, or one of the metal aluminium, is sometimes used as a support in place of the charcoal, but it is not often that there is any advantage in this substitution.

The way in which the charcoal is used and the chemical principles involved will be made clear by a few examples.

156.



The fragment of mineral used should be placed near one end of the rectangular piece of charcoal (see p. 124 and Fig. 156) and held so that the flame will sweep down the full length. This will give a volatile substance, if one is formed during the heating, the best opportunity to deposit when on the cooler surface. It is not necessary to make a deep hole; often a short scratch made across the charcoal with a sharp edge is sufficient: against this the fragment is blown by the flame. When the fragment persists in jumping off it may sometimes be held in place by a very little borax fused to it beforehand while it is held in the forceps.

Take a piece of stibnite (sulphide of antimony, Sb_2S_3), and place it on the charcoal and heat (gently at first, for it is likely to fly to pieces, or decrepitate). It will fuse very easily, for it stands first in the scale of fusibility, and while melting, and with further heating after fusion, it will give off a cloud of white fumes. These become dense, and collect as a white coating over the coal; the black surface seen through the white will on the edges give the effect of blue. If the heating is continued, the mineral will entirely disappear, or, in other words, it is entirely volatilized. Such a coating is called a *sublimate*, and in this case it consists of the *antimony trioxide* (Sb_2O_3) formed by the union of the antimony with the oxygen of the air; the compound produced at the same time by the combination of the sulphur and oxygen, sulphur dioxide (SO_2), goes off as a gas in the air. If now the reducing flame is thrown for a moment against the white coating, it is burned off with a bluish flame. The action of the flame is to reduce the oxide to the metal (Sb), which is instantly volatilized, and as it goes off it is again oxidized.

Again, take a fragment of orpiment, sulphide of arsenic (As_2S_3), and treat it in the same way. The result is somewhat similar; it fuses easily, giving white fumes (of As_2O_3), and it is also entirely volatile. But now a strong disagreeable odor will be perceived as the fumes are formed; this is usually described as a garlic, or alliaceous, odor; it is characteristic of arsenic, and is always produced when the metal is volatilized and *arsenic trioxide* (As_2O_3) formed. The odor serves to distinguish the two cases just described; but more than this, the white coating will be perceived to lie this time much farther from the flame than the oxide of antimony, because it is more volatile and can be deposited only where the coal is comparatively cool.

A third trial may be made with arsenopyrite. It gives off as it is heated a cloud of white fumes with the same peculiar penetrating garlic odor, and the white coating of arsenic trioxide forms at a distance on the coal. There is, however, a residue in this case which soon fuses to a grayish black globule which when cold is found to be magnetic, proving the presence of iron. The mineral consists of iron, sulphur, and arsenic (the formula is $FeAsS$). Part of the sulphur is driven off (as SO_2), and after some time all the arsenic, while a magnetic compound of iron and sulphur (with perhaps a little residue of arsenic) is left behind.

Another trial may be made with sphalerite or zinc blende, but to succeed now the mineral should be pulverized first, since it is infusible before the blowpipe and the compound is only with difficulty decomposed on charcoal. A little of the powder placed in the scratch and carefully heated (lest it be blown away) will cohere together and presently, if the flame is hot, a coating will be formed over the powder and just about it on the coal. If the powdered mineral is first mixed with two or three times its volume of sodium carbonate, it is then more easily decomposed and the sublimate obtained. This coating, which consists of the *oxide of zinc* (ZnO), has a bright canary-yellow color when hot, but becomes white on cooling. If the coating is thin, it might sometimes be mistaken for the charcoal ash (although good charcoal gives very little), and confirmatory evidence can be obtained by letting a drop of cobalt nitrate fall upon it, when, if again heated in the oxidizing flame, it will assume a bright green color characteristic of zinc. Still again, if the coating of zinc oxide, as at first obtained, is heated with the reducing flame, it is reduced, the zinc volatilized yielding a characteristic bluish-green flame. It may be repeated here that a fragment of calamine (zinc silicate) yields a similar sublimate, but the mineral itself becomes blue when heated after being moistened by the cobalt solution.

A fragment of galena should also be tried on charcoal. It will fuse very easily, and immediately about it there will form a yellow coating of the *oxide of lead* (PbO), while farther off there will be a white coating of lead sulphate ($PbSO_4$) formed by the union of the PbO and SO_2 in the presence of the oxygen of the air.

Further, lead is what is called an easily-reducible metal; that is, its compounds are rather easily changed to the metallic state under the action of heat, as on charcoal; hence continued heating yields globules of metallic lead. A little soda on the galena hastens the production of the metal, and at the same time it is noted that the yellow coating is more distinct, while the white fumes are nearly absent, for now the soda unites with the sulphur of the galena.

Again, a fragment of ruby silver—either the dark red (pyrargyrite) containing silver, antimony, and sulphur, or the light red (proustite) containing silver, arsenic, and sulphur—may be tried. It will fuse easily, and give off white fumes of either the oxide of antimony or arsenic according as to which mineral was in hand, and the distinction is easily noted as before described. A black globule will be left behind; and if now some sodium carbonate be poured over this on the coal, and the mass heated persistently till the globule is fused in it, presently, after rather long-continued blowing, a white globule, or perhaps several, will be seen moving about in the fused soda. By removing the fused mass from the charcoal and crushing it in a mortar, the *metallic silver* is readily separated. It will be found that the globule is white like silver, and remains bright (not oxidizing readily), and it is malleable. That it really is silver may be proved by chemical means, for it dissolves easily in nitric acid, and the addition to the solution of a drop of hydrochloric acid causes a white curdy precipitate of silver chloride to separate at once. The reddish coating, on the coal, of the silver oxide formed during the process is sometimes distinct. From some silver minerals, as the chloride, cerargyrite (also called horn-silver), the metal is obtained at once by heating on charcoal.

A mineral containing copper will yield metallic copper on charcoal when heated with the soda. This may be either in small globules or as a thin crust. When exposed to the air the copper becomes coated with the black oxide, but it is easily recognized, being malleable in the anvil, and showing when rubbed its peculiar red color.

Cassiterite or tin-stone, first powdered, for it is an infusible and refractory mineral, and then heated with soda, will give minute malleable globules of *metallic tin.* These are at first nearly as white as silver, but soon oxidize and become dull; with a little nitric acid in a watch-glass they yield an insoluble white powder of tin dioxide. The reduction is more easily accomplished if potassium cyanide is added to the mixture, but it is a very poisonous substance, and its use hardly to be recommended outside of the laboratory. The tin globules may not be very conspicuous in the soda, but are easily separated from the soda by crushing and washing in a mortar; the soda and charcoal are washed off and the heavy tin particles left behind.

Besides the coatings mentioned in these examples, the following must be mentioned:

Bismuth gives a volatile sublimate, which is dark orange-yellow when hot and lemon-yellow when cold. Mixed with equal parts of potassium iodide and sulphur and heated in the O. F., a beautiful red sublimate of bismuth iodide is deposited.

Molybdenum gives a sublimate which is yellow when hot and white on cooling; this is volatile in the O. F., leaving a copper-red stain of the oxide; if touched for a moment with the R. F. a beautiful azure-blue is obtained.

Cadmium gives a sublimate red-brown near the fragment and orange-yellow at a distance from it; the sublimate is volatile.

Selenium and selenides give a very disagreeable odor (like decaying horse-radish) which is highly characteristic.

Soda is also used on charcoal with the group of compounds called *sulphates,* to prove the presence of sulphur. A little of the pulverized mineral (as barite) fused with the soda yields a mass of a liver-brown color (called hepar), which, removed from the coal and placed with a drop of water on a silver coin, will stain it black. This is explained by the action upon the silver of the sodium sulphide formed on charcoal. It is essential that the soda itself should be free from sulphur; and further, since this may be contained in the illuminating gas employed, a preliminary trial should be made with soda alone; if this gives no action on the silver, then the final result with this, if showing the presence of sulphur, can be trusted.

6. Use of the Closed and Open Tubes.

The tubes in blowpipe work are chiefly used in the examination of minerals which yield on heating a volatile substance; this in most cases is condensed in the colder part of the tube. There is an important distinction to be observed between the use of the closed and the open tube. The *closed* tube contains but very little air, and this is driven out with the first puffs of gas from the heated mineral, and hence what goes on takes place without much effect from the oxygen of the air.

In the case of the *open* tube, on the contrary, if held in the proper inclined position, there is a constant stream of hot air (that is, of oxygen) which passes up the tube and over the heated mineral fragment. A few examples will show how this principle is applied.

Place a little fragment of *sulphur* in the closed tube and heat it gently. At once it is fused and converted into sulphur vapor which rises in the tube and soon condenses, giving a dark orange-red ring of liquid sulphur, which becomes light yellow as it cools and solidifies. Here there has been no change, simply the volatilization of the sulphur.

Now place a fragment in a rather large open tube, about an inch from the end; incline the tube as much as possible without causing the fragment to slip out, and heat it *very slowly*. The sulphur fuses as before, but the hot oxygen which passes over it unites with it, forming *sulphur dioxide* (SO_2), an invisible gas which rises through the tube and comes out of the open end, giving the usual sulphur odor (it should be inhaled with a little caution); further, the acid fumes of this gas will turn a piece of blue litmus-paper bright red. It is difficult to heat the sulphur slowly enough to prevent the formation also of a ring, as in the closed tube, simply because it is easily volatile; that is, it goes off into gas very readily, and the oxygen can hardly be supplied fast enough to oxidize it all.

As a second example, take a small piece of as pure cinnabar as can be obtained (it often occurs with clay as a gangue, as it is called, and this may give off water and obscure the result). The cinnabar is sulphide of mercury, HgS, a substance which is converted into vapor when heated out of contact with the air. In the closed tube we get at once a black ring, or sublimate, of *mercury sulphide* which, like the sulphur, was first volatilized and then condensed where the tube was cooler. This black coating becomes reddish if rubbed. In addition to it there may be also a faint gray deposit above of metallic mercury, because of the small amount of air in the tube at the start (see beyond).

Now place a fragment in the open tube and heat it, this time also very slowly and carefully. Gradually the cinnabar disappears, while the sulphurous fumes can be perceived at the end of the tube, as in the other case. But more than this, a little above the fragment a faint deposit begins to form, growing more and more distinct, and finally, when seen by reflected light, it appears as a shining mirror. This is *metallic mercury* in the form of minute globules coating the glass; that it is mercury can be proved even to the skeptical by cutting the tube carefully near the deposit (by first scratching it with a file) and then rubbing the deposit with a match-stick. The minute globules unite to form a few large ones which will run out of the tube, when tipped up, and on to the hand. As before remarked, a little of the metallic mercury may be noted for the same reason in the closed tube.

It is not difficult to explain what has happened in this case. The hot oxygen passing over the heated mineral has united with the sulphur to form sulphur dioxide (SO_2), while the mercury thus left alone has been driven off as vapor by the heat and collected where the cube was cool enough to allow of its condensation. Very likely in this case too, unless the heating is very slow, a little sulphide of mercury will go off without change and form a black ring in the closed tube, but by gradually heating this. keeping the tube in the same position, it is driven up the tube, more and more of the sulphur being oxidized, until nothing but the pure metallic mirror of the mercury is left.

This experiment succeeds best if the tube is first heated quite hot a little above the mineral and then the heating of the fragment carried on very slowly and carefully. If the powdered cinnabar be mixed with soda (first dried to expel the water), and then introduced into the *closed* tube* and heated, a sublimate of metallic mercury is very readily obtained.

Again, take a fragment of galena; in the closed tube it undergoes no change and no sublimate is formed. If, however, another fragment is placed in the open tube, although no sublimate is produced here, some of the sulphur is oxidized and the sulphurous fumes can be perceived by the odor or by their reddening effect on litmus-paper. This method is consequently a general method of testing for sulphur in the class of compounds called sulphides.

A fragment of orpiment, sulphide of arsenic, As_2S_3, heated in the closed tube is melted, volatilized, and forms a beautiful red ring of sulphide of arsenic. Heated in the open tube (very slowly), both sulphur and arsenic are oxidized; the sulphur gives as always SO_2, while the arsenic yields a white deposit of minute octahedral crystals of *arsenic trioxide* (As_2O_3) spangling in the light. This sublimate is very volatile and hence may be driven farther and farther up the tube when heated.

Arsenopyrite, FeAsS, in the closed tube gives a trace of a white sublimate of the oxide of arsenic, but more distinctly at first a dark red deposit of sulphide of arsenic (As_2S_3), which, if the heating is stopped and the tube allowed to cool, becomes a rich red color. If the heating is continued, the arsenic now goes off alone and forms a shining mirror of crystalline scales of metallic arsenic. The residue is magnetic and consists of iron and sulphur chiefly.

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* In a case like this where the substance is in powder, it can be introduced into the tube without soiling the tube (which is quite an important matter) if a little trough be made by folding once a narrow strip of paper ; then place the substance in this and insert it in the tube carefully, this being held in a horizontal position; now when the tube is turned into a vertical position the powder will fall to the bottom and the paper can be removed.

In the open tube, heated slowly, part of the sulphur goes off as sulphur dioxide, while the arsenic gives a white crystalline deposit of As_2O_3, and the same magnetic residue as before is left behind. This case illustrates again the important difference between the use of the open and closed tube.

Another good example is given by stibnite, Sb_2S_3. In the closed tube it is all volatilized and gives a dark red sublimate, most of which is a complex compound called an *antimony oxysulphide* ($2Sb_2S_3.Sb_2O_3$). The presence of this is explained by the fact that the oxygen in the small amount of the air contained in the tube is enough to unite with the sulphide of antimony and form the compound named.

In the open tube both sulphur and antimony are oxidized. The sulphur gives sulphur dioxide (SO_2) and the antimony gives *antimony trioxide* (Sb_2O_3), which forms as a dense white powdery deposit which is not volatile when heated by the flame. It is thus easily distinguished from the arsenic trioxide, which is crystalline and spangles in the light instead of being a dull powder; while the oxide of arsenic too is, as before stated, very volatile. The distinction between the sublimates of antimony and arsenic formed on charcoal should be recalled (see pp. 142, 143).

Of other rarer substances it may be mentioned that *selenium* gives a dark red, nearly black, sublimate in the closed tube with its peculiar disagreeable odor at the open end; in the open tube the sublimate is steel-gray, the upper edge red with perhaps white volatile crystals of the oxide.

Tellurium in the closed tube condenses in small drops with metallic luster; in the open tube a gray sublimate is formed which fuses to colorless drops, becoming solid on cooling.

Pyrite, iron disulphide, FeS_2, when heated in the closed tube gives off about half its sulphur which condenses in a ring like that just described. Heated slowly in the open tube, the sulphur which is driven off may be all oxidized to SO_2. A magnetic residue is left in both cases.

A few other uses of the tubes must be mentioned here.

A mineral containing *water*, when heated in the closed tube, gives off the water vapor which condenses as drops of water in the upper part of the tube. A change in the appearance of the mineral may take place at the same time. Thus a piece of limonite, or hydrated oxide of iron, gives off its water and turns red, for it is now the anhydrous oxide of iron, like hematite, which has a red powder. In a few cases, as with some sulphates, the water has an acid reaction and turns blue litmus-paper red. It may be added that the higher oxide of manganese (MnO_2—the mineral pyrolusite) gives off oxygen in the closed tube.

Fluorine is usually tested for in the closed tube, the powdered mineral being mixed with previously fused bisulphate of potash and then heated; the hydrofluoric acid given off attacks the glass or, as it is usually expressed, etches it.

A few minerals, as fluorite, *phosphoresce* in the tube, that is, give out a yellow or green light when held, after slight heating, in a dark spot. Also, as another phenomenon sometimes noted, the fragment when heated in the tube may glow brightly.

The more of the experiments with the minerals named the student performs the better, for knowledge thus obtained by experience is much better than knowledge learned from a book. A list of the minerals particularly useful for blowpipe work is given in an Appendix at the close of this book. Any one who has mastered the elements of blowpipe work and who is interested in learning more should turn to a manual of blowpipe analysis, where he will find many more tests and reactions and more minute directions for the work in general. The work of Professor Brush on Determinative Mineralogy may be particularly recommended.

7. Chemical Examination by Acids and other Reagents.

In addition to the various methods of chemical examination already described which can be made by means of the blowpipe, there are a few other chemical tests so easy to apply that the mineralogist should be in a position to use them. The reagents most needed are the three acids, hydrochloric, nitric, and sulphuric, perhaps also a little ammonia. In most cases it is best to use the strong acids, but often these diluted with an equal volume of water answer every purpose. A few test-tubes are also required, and sometimes a porcelain dish or casserole. The caution in regard to chemical reagents already mentioned (p. 127) is to be carefully observed.

Solubility in Acid.—The question as to whether a mineral is soluble in one of the acids named is often of great importance. To test the solubility hydrochloric acid is generally used, except with metallic sulphides and some other minerals containing prominently one of the heavy metals (lead, copper, silver, etc.); for these latter nitric acid is usually better. The mineral should in general be pulverized as finely as possible in the agate mortar and introduced into a large test-tube, some acid poured on, and the whole carefully heated over the Bunsen flame, the tube being shaken gently during the process.

It must be remembered here that the acid fumes in the air are injurious to breathe and will act corrosively upon surfaces of brass in the neighborhood; hence such tests can only be tried with caution unless the conveniences of the laboratory are at hand.

Various results may be noted during this trial:

A. The mineral may dissolve quietly with or without coloring the solution; this is true, for example, of hematite, also of many of the sulphates and phosphates.

B. There may be a bubbling off or effervescence of a gas. This gas is usually carbon dioxide or carbonic-acid gas

(CO_2); but may be hydrogen sulphide or sulphuretted hydrogen (H_2S). Also chlorine may be liberated, or reddish fumes of nitrogen.

C. There may be a separation of some insoluble substance, as sulphur, silica, etc. These points will now be spoken of more in detail.

Effervescence with Carbon Dioxide.—This resembles the bubbling observed, for example, in a glass of soda-water, due to the escape of this same gas liberated because of the relief of the pressure which kept it dissolved in the water in the tank. This is an easy and important test for the carbonates. Some of them dissolve in cold acid and even in lumps without being first pulverized. This is true of calcite, but is not true of dolomite and siderite, which require to be pulverized or heated, or both; hence this is used as a means of distinguishing between them. The carbonates of copper and lead should be tried with nitric acid.

Effervescence with Hydrogen Sulphide.—Most metallic minerals, as stated above, will be treated with nitric acid, but some not having a metallic luster, sphalerite for example, may be put into hydrochloric acid. In this case the reaction produces the gas hydrogen sulphide, while zinc chloride goes into solution. This gas bubbles off like carbon dioxide, but its disagreeable odor, resembling that of rotten eggs, shows at once what it is.

Chlorine, easily detected by its peculiar odor, is given off in some cases, as when the oxides of manganese are heated in hydrochloric acid.

Nitrogen Peroxide, giving a peculiar red color and suffocating odor, is liberated when many metallic sulphides (as chalcopyrite), also a few other compounds, as cuprite, are treated with nitric acid.

Separation of Sulphur.—A number of sulphides, as for example pyrite, dissolve in nitric acid with the separation of particles of sulphur which usually cling together and float on the liquid. It may be added that this is also true of chalcopyrite, or copper pyrites, but this, like other copper sulphides, gives a green solution which turns a deep fine prussian blue when ammonia is added in sufficient quantity to dissolve the precipitate that forms at first.

Separation of Tin Dioxide.—When metallic tin is treated with nitric acid, tin dioxide (SnO_2) is formed, which separates as an insoluble white powder.

Separation of Silica.—A number of silicates dissolve in hydrochloric acid with the separation of the silica, sometimes as a powder, sometimes as a slimy mass. Other silicates dissolve entirely; but if the solution is gently heated until part of the liquid has been evaporated off, a thick jelly is finally formed, so that the test-tube can be partially inverted without its flowing out. Such silicates are said to *gelatinize* with acid. This is true of calamine and a number of the zeolites; chabazite, on the other hand, is decomposed with the separation of slimy silica.

Difficultly-soluble or Insoluble Minerals.—A large number of minerals, even when pulverized, dissolve very little or not at all in strong hot acid. Quartz and corundum, for example; also the silicates, orthoclase, topaz, and many others, even when finely pulverized and long heated in strong acid, are not at all or only very slightly attacked. The question whether there has been partial solution is not always easy to answer, but can be decided if the liquid takes a distinct color, or more fully by filtering off the liquid from the undecomposed mineral, and then adding to it a few drops of ammonia, which, in general, will cause the bases which have gone into solution to separate as precipitates. To explain the various ways—simple, too, many of them—in which the bases present in the solution can be identified would take us too far into the subject of Chemistry. Do not forget, however, the test for *copper* just mentioned (p. 156), or that for *silver* given on an earlier page (p. 145). Further, attention may be called to the fact that, as a test for sulphuric acid or a sulphate, the addition, to a solution containing them, of a little barium chloride will cause a heavy white precipitate of barium sulphate to form.

CHAPTER VII.

DESCRIPTION OF MINERAL SPECIES.

THE following chapter gives descriptions of all the common species of minerals, with remarks, more or less brief, about many of those which are rarer. The system of classification is that spoken of on p. 120, in which the different compounds of the same metallic element are grouped together. The Silicates, however, many of which are complex in composition, containing more than one metal, are, with the exception of a few valuable ores, most conveniently included in a common section at the close of the chapter.

The several characters for each mineral species are enumerated in the following list:

Crystalline system; the characteristic angles and the common form, or habit, of the crystals; also the structure of the crystalline aggregates and massive varieties.

Cleavage; also fracture and tenacity.

Hardness (H.).

Specific gravity (G.).

Luster, color, streak, degree of transparency.

Other physical characters, as magnetism, etc.

Chemical composition and blowpipe characters.*

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* These last are also called *pyrognostic* characters because depending upon the application of heat (*πῦρ, fire*); this word is often contracted to *Pyr.*

The order in the above list is that which is at once the most convenient and scientific. In the account given of each species in the following pages, however, it is not attempted to adhere to this order strictly, as would be done in an advanced scientific work. On the contrary, so far as is possible in the brief space available, the aim is to make this account readable and to call attention especially to the characters most easy or most important to remember.

Further, in the description of many species no mention is made in regard to certain characters, which are relatively unimportant in these particular cases. Thus if the cleavage is not mentioned, it is because it is either not observed or too imperfect to be an important character. So, too, nearly all minerals are brittle, hence it is unnecessary to repeat this word in each case; but if the mineral is not brittle but malleable or sectile, this is stated and to be carefully noted. Again, if the streak is not given, it is to be understood to be *white* or nearly white, like that of most non-metallic minerals, even when the mineral itself in the mass has a deep color. Also all minerals if having a metallic luster are opaque. The localities of the species are mentioned, if at all, very briefly.

The student will find it easier to remember the characters of the different minerals, and a help in other ways, if, after studying the descriptions in the book and comparing them with such specimens as he has access to, he will make a brief tabular list of the characters for each species, something like that on the following page.

It is very easy to arrange a note-book (conveniently of the square letter size) for this purpose by ruling a series of

	Diamond.	Graphite.	Galena.	Sphalerite.
Cryst.system & common form	Isometric octahedron	Hexagonal tabular	Isometric cube	Isometric tetrahedral
Cryst. & mass.	——	Foliated	Granular-cleavable	Granular-cleavable
Cleavage	*Octahedral*	Basal	*Cubic*	*Dodecahedral*
Hardness, etc..	10!	1–2! flexible	2.5–3	3.5–4
Gravity.... ...	3.5	2.2	7.5!	4
Luster.	*Adamantine*	Metallic	Metallic	*Resinous*
Color	Colorless, yel'w	Black	Lead-gray	Yellow, brown, black, etc.
Streak.........	White	Black	Dark gray	White to brown
Comp.	Carbon	Carbon	PbS	ZnS
Pyr. etc.	Infusible	Infusible	Easily fusible	*Infusible*

parallel vertical columns, and the trouble of writing the list of characters over each time may be avoided if they are written on the edge of the first left page and the corresponding strip from a sufficient number of the sheets following neatly cut off. A little contraction of some common words will save space: hardness is often indicated by the letter H.; specific gravity by G.; yellow may be written *yw*, and so on. When a character is particularly important it may be underscored or followed by an exclamation point. It is not worth while to repeat in tabular form the *entire* description in the text; a little experience will soon show how much may be advantageously written down.

It will also be a useful exercise to fill out a similar column, so far as the individual case allows, for any species from the specimen itself, and then it may be compared with the description in the book, or the list in the student's note-book made out from the book. If the species was not known at first, this list of characters will often suffice to enable the student to determine it.

It is not necessary to *learn* by sheer effort of memory all the characters from the book at once; this would be difficult and tiresome; the most important can be learned (and first the chemical composition), while the knowledge of most of the physical characters is rather to be acquired gradually by the repeated handling of the specimens themselves.

The following is a summary of the species included in the pages which follow,* arranged, except for the silicates, under the prominent element of which they are compounds. Many other species are mentioned briefly in the text, though not included here. The student should read again the brief statements in regard to the classification of the chemical elements and the prominent groups of chemical compounds given on pp. 109 to 116.

It may be interesting here to recall the old alchemistic method of designating the chief metals by referring them to one of the members of the Solar System, as follows: the Sun, gold; the Moon, silver; the planet Mercury, mercury; Venus, copper; Mars, iron; Jupiter, tin; Saturn, lead. Other prominent metals are platinum, zinc, and aluminium.

CARBON:	Diamond.
	Graphite.
SULPHUR:	Native Sulphur.
HYDROGEN:	Ice (and water).

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* A list is given in the Appendix of those of the species here enumerated which it is most important for the student to have in his collection.

ARSENIC:	Native Arsenic.
	Realgar and Orpiment, Arsenic sulphides
ANTIMONY:	Native Antimony.
	Stibnite, Antimony sulphide.
BISMUTH:	Native Bismuth.
MOLYBDENUM:	Molybdenite, Molybdenum sulphide.
GOLD:	Native Gold.
	Sylvanite, Gold telluride.
PLATINUM:	Native Platinum.
SILVER:	Native Silver.
	Argentite, Silver sulphide.
	Pyrargyrite, Sulphide of silver and antimony.
	Proustite, Sulphide of silver and arsenic.
	Cerargyrite, Silver chloride.
MERCURY:	Native Mercury.
	Cinnabar, Mercury sulphide.
COPPER:	Native Copper.
	Chalcocite, Copper sulphide.
	Bornite and Chalcopyrite, Sulphides of copper and iron.
	Tetrahedrite, Sulphide of antimony and copper.
	Cuprite, cuprous oxide.
	Malachite and Azurite, Carbonates of copper.
	Dioptase and Chrysocolla, Silicates of copper.
LEAD:	Native Lead.
	Galena, Lead sulphide

	Jamesonite and Bournonite, Sulphides of antimony and lead.
	Pyromorphite, Lead phosphate.
	Mimetite, Lead arsenate.
	Vanadinite, Lead vanadate.
	Cerussite, Lead carbonate.
	Anglesite, Lead sulphate.
	Also Crocoite, Lead chromate; Wulfenite, Lead molybdate, etc.
TIN:	Cassiterite, Tin dioxide.
TITANIUM:	Rutile; also Octahedrite and Brookite, all alike Titanium dioxide, TiO_2.
URANIUM:	Uraninite.
	Torbernite, Autunite, Uranium phosphates.
IRON:	Native Iron.
	Pyrrhotite, Iron sulphide.
	Pyrite and Marcasite, Iron disulphide.
	Arsenopyrite, Iron sulph-arsenide.
	Hematite, Iron sesquioxide.
	Magnetite, Magnetic iron oxide.
	Franklinite, Iron-zinc-manganese oxide.
	Chromite, Iron-chromium oxide.
	Limonite, Hydrated iron oxide.
	Siderite, Iron carbonate.
	Also Columbite, Iron niobate (columbate) and Wolframite, Iron tungstate; Triphylite, Phosphate of iron and lithium.
NICKEL:	Millerite, Nickel sulphide.
	Niccolite, Nickel arsenide.
	Genthite and Garnierite, Nickel silicates.

COBALT:	Linnæite, Cobalt sulphide.
	Smaltite and Cobaltite, Arsenides of cobalt.
	Erythrite, Cobalt arsenate.
MANGANESE:	Pyrolusite and Manganite, Oxides of manganese.
	Rhodonite, Manganese silicate.
	Rhodochrosite, Manganese carbonate.
ZINC:	Sphalerite, Zinc sulphide.
	Zincite, Zinc oxide.
	Willemite and Calamine, Zinc silicates.
	Smithsonite, Zinc carbonate.
ALUMINIUM:	Corundum, Aluminium oxide.
	Spinel, Oxide of magnesium and aluminium.
	Cryolite, Fluoride of aluminium and sodium.
	Turquois and Wavellite, Aluminium phosphates; Amblygonite, Phosphate of aluminium and lithium.
CALCIUM:	Fluorite, Calcium fluoride.
	Calcite and Aragonite, Calcium carbonates.
	Apatite, Calcium phosphate.
	Anhydrite, Calcium sulphate.
	Gypsum, Hydrated calcium sulphate.
	Scheelite, Calcium tungstate.
MAGNESIUM:	Brucite, Hydrated magnesium oxide.
	Magnesite and Dolomite, Magnesium carbonates.
	Boracite, Magnesium borate.

Barium: Barite, Barium sulphate.
Witherite, Barium carbonate.

Strontium: Celestite, Strontium sulphate.
Strontianite, Strontium carbonate.

Sodium and Potassium: Halite or Rock Salt, Sodium chloride.
Borax, Sodium borate.
Sylvite, Potassium chloride.

Silicon: Quartz, Silicon dioxide.
Opal, Hydrated silicon dioxide.

Silicates:* *Feldspars:* Orthoclase (and Microcline), Albite, Anorthite; also Oligoclase, Labradorite.
Pyroxene (Diopside, Salite, Augite, etc.).
Amphibole or Hornblende (Tremolite, Actinolite, Asbestus, etc.).
Beryl.
Garnet (Grossularite, Almandite, etc.)
Micas: Muscovite, Biotite, Phlogopite, Lepidolite.
Chlorites: Clinochlore, etc.
Chrysolite.
Zircon.
Scapolite.
Vesuvianite.
Epidote.
Tourmaline.
Topaz.

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* The composition of the following minerals is in many cases too complex to be given briefly here.

Titanite or Sphene.
Andalusite, Sillimanite and Cyanite.
Staurolite.
Talc.
Serpentine.
Datolite.
Prehnite.
Apophyllite.
Pectolite.
Zeolites: Thomsonite, Natrolite, Analcite, Chabazite, Stilbite, Heulandite.

CARBON.

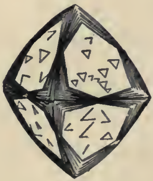
Diamond. Carbon, C.

The DIAMOND is usually found in distinct isolated crystals, most of them very small, but sometimes as large as a robin's egg or even larger. The crystals are commonly octahedrons, though less often some of the other forms of the isometric system (p. 22) are observed. The natural crystals before cutting—"rough diamonds" they are called—frequently have rounded edges and curved faces, or the faces show little pits like the etchings spoken of on p. 64. This is illustrated in Fig. 157, while Fig. 158 shows a hexoctahedron with convex faces. There are also forms with irregular structure, occasionally as round as peas, and one peculiar kind is massive and dull black in color.

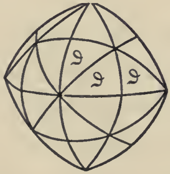
The crystals have perfect cleavage parallel to the octahedral faces, which the lapidary makes use of to bring a stone into the form best suited for cutting. The hardness is 10, or higher than that of any other species, and the specific gravity is also high, 3.5 (see p. 84). The luster is very brilliant and of the peculiar character named (from this species) *adamantine;* the brilliancy of the diamond, however, is much greater when cut with many facets than in the natural crystals. The most highly prized stones are colorless and clear as water (then said to be "of the first water"); a pale yellow color is very common, and sometimes other colors, in pale shades, as green, pink, and blue, are observed; rarely it is black and dull.

The diamond consists of pure carbon, and has thus the same composition as a piece of charcoal. It is infusible as is charcoal, and is not acted upon by acids; but it is unlike charcoal in that it does not burn. When heated very hot, however, as in the electric arc, it is slowly consumed, forming, like burning charcoal, carbon dioxide or carbonic-acid gas (CO_2). Heated out of contact with the oxygen of the air it is converted into a mass resembling coke.

157.



158.



The diamond has been found mostly in gravel deposits, or the rocks formed by their consolidation, and but little is known about its real home or the way it was made. Formerly it was obtained in great quantities in India; later Brazil afforded many of the gems, but both these countries now yield comparatively few. The great region which produces the diamond at the present time is in South Africa, some eight hundred miles from Cape Town, where it occurs along the Vaal River, and in larger quantities especially in the neighborhood of Kimberly, in peculiar oval regions called "pans." Here the diamond mines have been worked for about twenty-five years and a vast number of stones have been found and brought to market. Think of more than *eight tons* of diamonds obtained during this time!

Everybody knows of the use of the diamond for jewelry, for which its brilliancy, hardness, and comparative rarity peculiarly fit it. Many of the great diamonds of the world have a long and fascinating history of their own, which would fill a large volume if all were told of the way in which they have repeatedly changed hands until they have come into the possession of royalty, as the famous "Kohinoor" among the crown jewels of England, or the "Florentine" of Austria and the great "Orlov" diamond of Russia. Diamonds are also used for cutting glass and, in the form of powder, in grinding diamonds and other hard gems. The black coal-like diamonds, set in a collar and rotated rapidly by machinery, as a diamond drill, cut quickly through the hardest rocks, leaving a core behind, which is raised at intervals; a well-boring is thus easily made.

Graphite or Plumbago. Carbon, C.

GRAPHITE, or Plumbago as it is often called, is usually found in massive forms which may be separated easily into thin leaves or plates and hence are said to be foliated; sometimes also it is finely granular and compact. Rarely the plates are distinct and separate and show a regular six-sided outline, whence it is referred to the hexagonal system; it is then seen to have perfect basal cleavage.

It is sectile and so soft as to make a mark on paper and to feel greasy to the hand (H. = 1 to 2), and its specific gravity is only 2.2. It has a metallic luster and an iron-black or steel-gray color and streak; it is perfectly opaque.

Graphite has the same composition as the diamond, consisting also of nearly pure carbon; it is, however, a different substance in its physical characters and is hence a distinct mineral. Note that they differ in crystalline form; also the diamond is *hard* and *heavy*, while graphite is *soft* and *light*.

It is also infusible like the diamond, and is not attacked by acids, but may be converted into carbon dioxide (CO_2) by heating to a very high temperature in the air.

Graphite is commonly found in the crystalline rocks called gneiss, sometimes scattered in scales, but occasionally in large beds that can be mined; it is also found in scales in crystalline limestone, and is often formed in an iron furnace. It is largely mined at Ticonderoga, N. Y.; also in Eastern Siberia, and in Ceylon.

Graphite is the so-called *black lead* of our "lead-pencils" (but it is only like lead in its color), and would be mined for this purpose if for no other. It is used as an excellent lubricator because of its smooth soapy character when pulverized; also, mixed with clay, for making crucibles because it is infusible and not affected by the heat of an ordinary furnace; in electroplating because it is a conductor of electricity.

Carbon is also the element which forms the essential part of the different kinds of coal and of mineral oil or petroleum.

Anthracite, the coal of eastern Pennsylvania, contains 85 to 95 per cent of carbon and has a bright shiny surface and conchoidal fracture; it burns with a pale feeble flame without smoke.

Bituminous coal is black to dark brown in color, often dull and with a pitchy luster; it contains less carbon than anthracite (usually 75 per cent) and more hydrogen and oxygen; it burns with a yellow smoky flame. Brown coal, or lignite, has a brown color, dull luster, often retains the structure of the original wood and contains still less carbon, sometimes only 50 per cent. These different kinds of coal and others related to them, though of great economic value, are not properly mineral species, since they have no definite chemical composition. The same remark applies to asphaltum, bitumen, mineral wax or ozocerite, the many kinds of mineral resins including amber, and finally mineral oil or petroleum, all of which consist chiefly of carbon.

The element carbon is also present in the large group of minerals called *carbonates*, of which calcite, including common limestone, is much the most important.

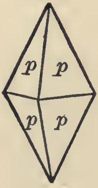
SULPHUR.

Native Sulphur. S.

Sulphur is another of the chemical elements occurring in nature. It is found in crystals of the orthorhombic system; a common form is an acute rhombic pyramid (Fig. 159) with terminal angles of 106½° and 85°. Figs. 160, 161 are also common forms. It also occurs in masses and in powder. It is soft (H. = 1.5 to 2.5) and, though brittle under the blow of a hammer, is easily cut by the knife; the specific gravity is about 2. It has a resinous luster and a bright sulphur-yellow color and streak. The crystals are often clear and transparent. It consists of pure sulphur, and is remarkable among minerals because when heated it takes fire and burns with a pale blue flame, giving a gas (sulphur dioxide, SO_2) which has a very suffocating odor familiar to all who use sulphur matches.

Sulphur is for the most part found in volcanic regions, as in Sicily and the Sandwich Islands; also in beds associated with gypsum. It is used for making sulphur matches; it is one of the three substances of which gunpowder is made (with charcoal and niter); it is used in preparing the rubber gum for overshoes and other purposes; also in making sulphuric acid and in other ways. It is in fact a most important mineral.

159.



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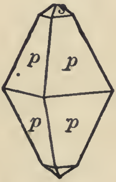

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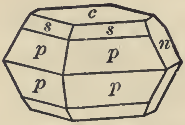


Sulphur also occurs abundantly in nature, not as an element, but in combination with the metals forming the very large and important class of *sulphides*, as lead sulphide, PbS, the mineral galena. It also forms the acid, sulphuric acid, H_2SO_4, the salts of which are the important class of *sulphates*, as barium sulphate, $BaSO_4$, the mineral barite.

Ice. Hydrogen oxide, H_2O.

Although it cannot be preserved in a mineral cabinet, ICE, the solid form of water, is as truly a mineral as diamond or quartz. It occurs in crystalline forms of the hexagonal type, often of great complexity and beauty, as seen in snow-crystals. These, as stated on p. 17, are formed in the atmosphere direct from the water vapor. Some of the forms are shown in figure on p. 17. The ice-grains that make the pellets of hail, not infrequently occurring with summer thunder-storms, are also occasionally in clusters of crystals, somewhat resembling the hexagonal pyramids of quartz, though this is the exception; generally there is simply a concentric concretionary structure. The ice of the pools and ponds is always crystalline, though it is usually only in the first stages of the process of freezing that the crystals are separately visible. This process of solidification goes on, as every one knows, at a temperature of 32° Fahrenheit (0° Centigrade). The hardness of ice near the freezing-point is 1.5, but this increases at lower temperatures. The specific gravity is about 0.92, so that it floats in the water with a little more than nine tenths of its bulk submerged. Water expands, therefore, largely on freezing and exerts a great force on confining surfaces. One consequence of this is the breaking of vessels, water-pipes, etc., when the water they contain is frozen. In nature ice is on account of this property a powerful agent in pulling rocks to pieces, the water creeping into the cracks, especially into the narrow ones, by capillarity, and when it solidifies the rock masses are slowly but surely wedged apart.

Water consists chemically of hydrogen and oxygen, combined in the ratio of 2 : 1 by volume, or 11.1 : 88.9 by weight.

TELLURIUM.

Carbon in its two forms, the diamond and graphite, and sulphur belong, as was stated on p. 102, to the *non-metals* among the chemical elements. Intermediate between them and the true metals, like gold and silver, come several elements which occur in nature, namely, tellurium, arsenic, antimony, and bismuth.

TELLURIUM has a bright tin-white color and a metallic luster, though, unlike the true metals, it is rather brittle; it is occasionally found in Colorado. This element is of little economic importance, but is interesting because it is the only one with which gold occurs combined in nature, in some of the rare minerals called tellurides (see p. 181).

ARSENIC.

ARSENIC is found occasionally as a mineral and then called NATIVE ARSENIC. It has a metallic luster and tin-white color, but soon tarnishes on the surface to a dull dark gray; it is also brittle. It generally occurs showing a fine granular structure when fractured, and the masses commonly have a reniform or botryoidal surface.

Arsenic is used with copper and tin to form the alloy called speculum metal, useful for metallic mirrors because of the brilliant surface it takes when polished. The lead employed for making shot contains a small amount of arsenic. The compounds of arsenic find various uses, as pigments, (sulphide); as a preservative; a poison for insects (white arsenic and Paris green); also in dyeing, medicine, etc.

Realgar, Orpiment. Sulphides of Arsenic.

Two important but rather rare minerals containing arsenic are the sulphides, Realgar, AsS, and Orpiment, As_2S_3.

REALGAR is found in transparent monoclinic crystals and massive forms of a beautiful aurora-red color. It is soft and sectile (H. = 1.5–2) and has a specific gravity of 3.5; the luster is resinous. Its composition is AsS, or arsenic monosulphide, which gives the percentage composition: Sulphur 29.9, arsenic 70.1 = 100.

ORPIMENT, named from the Latin auripigmentum, or Gold pigment (also called King's yellow), is of a beautiful golden yellow. It is generally found in masses showing a foliated structure and with one perfect cleavage so that it can be split off into thin flexible leaves. Distinct crystals of orpiment are very rare; they belong to the orthorhombic system. It is soft (H. = 1.5–2), sectile, and the specific gravity is about 3.5.

The composition is As_2S_3, or arsenic trisulphide, which gives: Sulphur 39.0, arsenic 61.0 = 100. Its behavior in the closed and open tubes is mentioned on p. 150; on charcoal it is all volatilized, giving the characteristic garlic odor of arsenic and white fumes of the oxide (As_2O_3).

Arsenic is present in a great many other minerals. It forms with the metals a series of compounds called *arsenides,* of which arsenopyrite and cobaltite are examples. It forms with sulphur a number of compounds of the metals, as proustite. There are also a series of salts called *arsenates,* one of which is the lead arsenate mimetite; another is the cobalt arsenate, erythrite.

White arsenic, or the "arsenic of the druggist," is the oxide, As_2O_3, which occasionally occurs as a mineral (then called ARSENOLITE). It is formed whenever metallic arsenic or an arsenide is roasted in the air. In the open tube it is often obtained in spangling octahedral crystals (see pp. 17 and 150).

ANTIMONY.

ANTIMONY, like bismuth, is usually included among the metals, for it has a high metallic luster, although its structure is crystalline and it is quite brittle. It is a very easily fusible metal and is useful in the arts because of the alloys which it forms with lead and tin, to which it imparts greater hardness and durability. Thus type-metal is an alloy of one part of antimony to three or four of lead. Britannia metal, often used as the base of plated silverware, is an alloy of antimony with brass, tin, and lead. Babbitt metal, used for bearings, is another alloy of antimony with tin and copper. Tartar emetic, used in medicine, is tartrate of antimony and potassium.

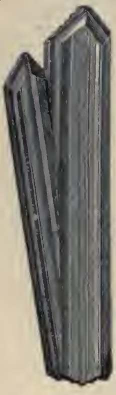
Native Antimony, Sb.

NATIVE ANTIMONY is a bright tin-white mineral with metallic luster, and commonly showing brilliant cleavage surfaces; rhombohedral crystals are rare. Its hardness is 3 to 3.5, and the specific gravity 6.7. It is not a common mineral, but is found in New Brunswick in some quantity, in California and elsewhere. Heated on charcoal it fuses and goes off entirely in white fumes of the trioxide, Sb_2O_3; in the open tube dense white fumes of this oxide are also deposited (see p. 151).

Stibnite, or Antimony Glance. Antimony Sulphide, Sb_2S_3.

STIBNITE, the sulphide of antimony, is its commonest and most important ore. It is found in prismatic crystals of the orthorhombic system, often spear-shaped at the ends (Fig. 162). These crystals are frequently acicular and arranged in radiating groups, or again they may be very large; the mines in Japan have afforded specimens magnificent in size and brilliancy of luster.

162.



The crystals have very perfect cleavage, parallel to one vertical edge, and the surfaces formed by this are smooth and highly polished. Besides the prismatic crystals, stibnite also occurs in massive forms, generally columnar in structure and then also showing the perfect cleavage; but also sometimes compact and granular and then the cleavage is not apparent.

The hardness is only 2, so that it is scratched by the nail and leaves a mark on paper; it is quite sectile. It is not, however, to be confounded with graphite, which is much more soft and greasy in feel and marks the paper without the slightest tendency to tear it. The specific gravity of stibnite is about 4.6. The luster is metallic and on a fresh surface—particularly a cleavage surface—it is very brilliant, as already noted. The color is a bluish gray, but less blue than galena, with which it is sometimes confounded (but note the difference in cleavage); the streak is nearly black.

Stibnite is the sulphide of antimony (antimony trisulphide), Sb_2S_3; this gives the percentage composition: Sulphur 28.6, antimony 71.4 = 100. Heated on charcoal it fuses very easily and gives off fumes of the oxide of antimony (Sb_2O_3), which form a thick coating at a little distance; after a few moments the fragment is entirely volatilized. If the reducing flame is thrown for a moment on the coating, it is burned off with a greenish-blue flame. In the open tube, heated slowly, the same dense deposit or sublimate is formed in the cold portion; this is powdery and not readily volatile like the somewhat similar white oxide of arsenic. In the closed tube a dark red sublimate of antimony oxysulphide is formed (cf. p. 151).

Antimony also enters into a number of other minerals, as pyrargyrite, or dark red ruby-silver; also tetrahedrite, or gray copper, jamesonite, bournonite, etc. These are further mentioned under the metals of which they are compounds; for a description of the other related minerals reference must be made to larger works on mineralogy.

BISMUTH.

Bismuth is silver-white in color with a reddish tinge and has a bright metallic luster; it is rather brittle and shows a crystalline structure with perfect cleavages; it is, however, nearer to the true metals than either arsenic or antimony. Native bismuth is a rare mineral, and its compounds, chiefly among the sulphides, are also too rare to be particularly mentioned here. The sulphide of bismuth, or bismuthinite, resembles stibnite rather closely in physical characters.

Bismuth is an even more fusible metal than antimony, and the alloys which it forms are remarkable for their low melting-points; an alloy of bismuth with lead and tin fuses at a temperature below that of boiling water; another alloy of the same metals in different proportions is used as a kind of solder. Some bismuth alloys have the curious property of *contracting* instead of expanding with heat. Bismuth is also employed in medicine in the form of the subnitrate; another compound is used as a cosmetic; other uses are in calico-printing, to give luster to porcelain, etc.

MOLYBDENUM.

Molybdenite. Molybdenum sulphide, MoS_2.

MOLYBDENITE is the sulphide of the rare element molybdenum. It is not a common mineral, but is found in small quantities in a good many localities, chiefly in crystalline rocks like gneiss. Like graphite, which it much resembles, it occurs in foliated masses or in crystalline plates having a hexagonal outline; rarely in distinct hexagonal crystals. It is also very soft (H. = 1–1.5) with a soapy feel and leaves a trace on paper. It has a bluish-black color and metallic luster. The color, however, is distinctly bluer and the specific gravity (G. = 4.7) is higher than that of graphite. bluish lead grey.

Graphite is a brownish black color

The composition of Molybdenum disulphide, MoS_2, gives: Sulphur 40.0, molybdenum 60.0 = 100. Heated in the open tube or on charcoal it gives off strong sulphur fumes and yields a deposit, which is pale yellow or white, of molybdic oxide; this coating on charcoal, if touched with an intermittent blowpipe flame (reducing flame) becomes a bright blue (see p. 146).

Molybdenum also occurs in the salts called molybdates, of which lead molybdate, the mineral wulfenite, is the most common.

GOLD.

Native Gold, Au.

GOLD is the most highly prized of the metals, valued because it serves as the money of all civilized people,* and because of its use for ornaments, as watches, rings, etc.

It is sometimes found in isometric crystals, as in octahedrons, but usually in plates or scales or wirelike forms; also in larger masses—sometimes very large—called nuggets (see Fig. 163). It is soft (H. = 2.5 to 3) and can be cut by the knife. It is highly malleable and ductile and especially remarkable because it can be hammered out into very thin sheets; the skillful gold-beater can make the plates so thin as to transmit a faint greenish light.

Gold is very heavy and when pure has a specific gravity a little over 19. The luster is metallic and the color the familiar gold-yellow, but varying with the other metals alloyed with it. The native gold practically always contains some silver and often a good deal, and then it has a paler color and lower density; with sixteen per cent of silver the specific gravity is only 17. The gold used for watch-cases and for ornaments, on the other hand, is often alloyed with copper and hence has a reddish color. Gold is not attacked by the ordinary acids, but is dissolved in a mixture of nitric and hydrochloric acids (called aqua regia).

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* The gold coin of the United States and France contains gold and copper in the ratio of 9 to 1; that of England in the ratio of 11 to 1.

Gold occurs mostly in veins in the older crystalline rocks, especially associated with quartz; gold quartz is quartz—often milky—which either shows little particles of gold scattered through it, or from which gold can be obtained—even if not visible to the eye—after the rock is crushed to powder and then washed to remove the lighter material. A large part of the gold of the world has been obtained from the sands and gravels produced by the disintegration of gold-bearing rocks. These gravels in the bed of a stream may be washed by the miner in his pan; or, on a large scale, where a powerful stream of

163.

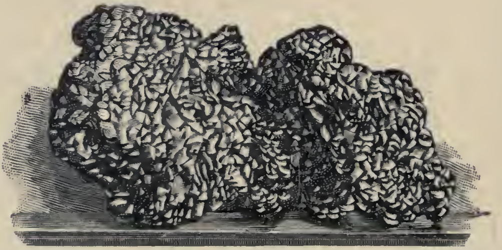

Figure of a model of a large Australian gold nugget weighing 2166 ounces and valued at about 40,000 dollars.

water is thrown against the gravel bank, carrying away the lighter rock and leaving the heavy gold particles behind, usually in the form of little flattened scales. The finest particles preserved are called "gold-dust."

The chief gold-producing countries at the present time are the United States, especially in the State of California, where gold was discovered in 1848; in Australia, Russia, South Africa, where recent discoveries have proved to be very important. Gold is also produced in South America, China, British India, Canada; to a limited extent in Germany and Austria-Hungary and some other countries.

It is remarkable that almost all the gold of the world—and an amount valued at about $180,000,000 was mined in 1894—is obtained from the native metal; for minerals containing gold are very rare. The only ones known, besides the auriferous pyrite, arsenopyrite, etc., are a few compounds with tellurium called tellurides.

The best known of these gold tellurides is SYLVANITE, a silver-white mineral with brilliant metallic luster, soft (H. = 1.5–2) and heavy (G. = 8.0). It was long since found in Transylvania (whence it takes its name), but also occurs in Colorado. Another name for it is *Graphic Tellurium,* because of the curious forms, resembling written characters, that the crystals sometimes take on a rock surface.

PLATINUM.

Native Platinum, Pt.

PLATINUM is reckoned among the nobler metals with gold, and like it is not attacked by any of the single acids.

It has a rather dull gray color, and is not a beautiful metal, although now more highly valued because of its practical uses than any of the metals except gold.

It is rarely found in isometric crystals, as in cubes, more commonly in scales or in larger masses (up to twenty pounds) called nuggets, washed out of the gold sand. It has a hardness of 4 to 4.5, and a specific gravity varying from 14 to 19 according to the amount of other metals alloyed with it chemically. Pure platinum, as obtained in the laboratory, has a specific gravity of 21 to 22, for native platinum is not the pure metal, but is found by the chemist to contain iron, sometimes in large amount (nearly 20 per cent), and also a number of rare metals, as palladium, rhodium, and others.

Platinum is a highly useful metal. The fact that it is fused with great difficulty and is not attacked by ordinary chemical reagents makes it very valuable both to the chemist in the laboratory and in the chemical manufactories, where crucibles and dishes are made of it. It is also largely used by dentists. It has come into use of recent years for the attachments to the ends of the carbon wire in the incandescent electric lamp. Only a very minute quantity is required in each case, but so many lamps are called for that the demand is very great, and as only a small amount is mined—chiefly in the Ural Mountains in Russia—the price has risen much higher than formerly. Platinum has been used to a small extent for coins. Between the years 1828 and 1845 in Russia a considerable amount was in circulation, but the coins were recalled and the experiment has not been repeated.

Platinum, like gold, does not readily combine with other elements, and in nature the only compound known is an arsenide ($PtAs_2$), called SPERRYLITE; this is found in very small quantities in a mine near Sudbury, Ontario, Canada. It is interesting to note that the name platinum is derived from *plata*, the Spanish word for silver, since it was regarded in South America at the time of its discovery (1735) as an impure ore of that metal.

IRIDOSMINE is a compound of the rare metals iridium and osmium resembling platinum, but of a whiter color. It is found under similar conditions in the form of flattened scales in gold-washings. It is very hard, and on this account has been used for the points of gold pens.

SILVER.

SILVER is one of the precious metals, useful alike as money,* for ornaments of many kinds, and for utensils. The color is a fine silver-white when perfectly fresh, but unfortunately it is very easily tarnished, and the presence of a very little sulphur or sulphur gases in the atmosphere soon turns it black.

Native Silver, Ag.

NATIVE SILVER is not an uncommon mineral, although the world's supply of the metal comes chiefly from its ores. It is like gold in its occurrence, sometimes, though rarely, in distinct isometric crystals, more frequently in arborescent or branching groups, in plates and scales or wirelike forms (Fig. 164); sometimes in fine threads.

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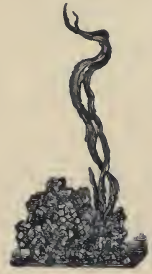
* The silver coin of the United States and France contains silver and copper in the ratio of 9 to 1; that of England in the ratio of 12½ to 1.

164.



WIRE SILVER.

Its hardness is 2.5 to 3; it is highly malleable and ductile, and is the best known conductor for both heat and electricity. Its specific gravity is 10.6 when pure, but higher when alloyed with gold, as often in nature.

Native silver occurs rather abundantly in nature, as in Mexico, Arizona, Norway, also in South America and Australia.

Silver is readily dissolved by nitric acid, forming silver nitrate, and from its solution the addition of any compound containing chlorine, as hydrochloric acid or sodium chloride, causes part to separate as a white curdy deposit of silver chloride. This is a very delicate test for silver.

Argentite, or Silver Glance. Silver sulphide, Ag_2S.

Argentite is named from the Latin word of silver, *argentum.* It is a very valuable though not very common ore, since when pure it contains 87 per cent of metallic silver. It is found in cubic or octahedral crystals, often growing together in branching forms; more commonly it occurs simply in masses.

The hardness is about 2, and the specific gravity 7.3. It is readily cut with the knife, almost like lead, and hence is said to be eminently sectile, also flattening to some extent under the hammer, while almost all other sulphides are brittle and break at once with a blow into fragments. The luster is metallic, and the color and streak grayish black.

The formula is Ag_2S, or silver sulphide, which gives: Sulphur 12.9, silver 87.1 = 100. Heated by the blowpipe flame on charcoal, the sulphur is easily roasted off and a little silver ball left behind, which can be tested chemically by dissolving in nitric acid, and adding a drop of hydrochloric acid, as before mentioned.

There are a number of other sulphur compounds of silver, but most of them are too rare to be mentioned fully here. The most interesting of these are the two beautiful minerals called red-silver ore or ruby-silver, that is, the dark red-silver ore, PYRARGYRITE, which contains sulphur, antimony, and silver, and the light red-silver ore, PROUSTITE, which contains sulphur, arsenic, and silver.

Both these minerals crystallize in hexagonal prisms with rhombohedral or scalenohedral faces, and they resemble each other closely in their characters, as hardness 2.5, specific gravity 5.8 pyrargyrite and 5.6 proustite. The color of pyrargyrite is dark red, often black, with nearly metallic luster on the surface, while proustite is bright red. Both have a red streak.

Heated on charcoal, pyrargyrite gives off dense antimony fumes (Sb_2O_3), while proustite yields arsenical fumes (As_2O_3) easily recognized by their garlic odor. Both minerals give a globule of silver if roasted with soda on charcoal (see p. 144).

Cerargyrite, or Horn-silver. Silver chloride, $AgCl$.

The name CERARGYRITE, translated into English, means *horn-silver*, and it is so called because of its appearance and the ease with which it is cut by a knife.

It is found in cubic crystals rarely, more commonly in scales, plates or masses. The hardness is 1 to 1.5, and the specific gravity 5.5. It is remarkable for being perfectly sectile, cutting with a knife like a piece of lead or wax. The luster is adamantine and the color white or pale gray or green; it is transparent to translucent.

It is a rather rare but highly valuable silver ore, the percentage composition being: Chlorine 24.7, silver 75.3 = 100. Roasted alone on charcoal the chlorine is easily driven off and a globule of silver left behind.

MERCURY.

MERCURY is a remarkable metal, because it is a liquid at all ordinary temperatures, only freezing, or becoming solid, at − 40°. It has a silver-white color and brilliant metallic luster, and is so mobile that from early times it has been called *quicksilver*. Its density is high, 13.6, or higher than silver (10.6) and lead (11.4), and for this reason and because of its liquid form it is of great value for scientific purposes. It is used in most thermometers and barometers and is employed in many experiments in the physical and chemical laboratories. It also has the property of forming a pasty mass or amalgam with some of the other metals, as gold and silver (also copper, zinc, tin, etc., but not iron), and is hence of great value in separating them from the rock in which they occur. For this purpose the rock is ground into powder, the greater part of the loose material washed off, and then the remainder is agitated with mercury. The amalgam, which forms, is collected, and by heat the mercury is driven off to be collected again in cool chambers for further use, and the gold and silver are left behind. Ordinary mirrors are made of glass backed with an amalgam of mercury and tin. The sulphide of mercury is the valuable pigment called *vermilion.* Mercury in various forms is also used in medicine, but in minute doses, for it is an active poison. Corrosive sublimate is a chloride of mercury.

NATIVE MERCURY is a rare mineral in nature, though occasionally found in minute globules scattered through the rock; the common ore is cinnabar.

NATIVE AMALGAM is a rather rare mineral containing mercury and silver, but in very varying amounts.

Cinnabar. Mercury sulphide, HgS.

✳

CINNABAR, the sulphide of mercury, and sometimes called *natural vermilion,* is found in masses of a fine red color, and sometimes also in small rhombohedral or prismatic crystals. The hardness is 2 to 2.5, and the specific gravity is about 8, or above that of metallic iron (7.8). The great weight of a specimen cannot escape the observer and is a striking character; in some cases, however, if the cinnabar is not a pure solid mass, but only scattered through a light clayey gangue, the density of the whole may be much lower than 8.

The luster is adamantine and the color bright cochineal-red, sometimes becoming dull and dark; the streak is scarlet; crystals are usually perfectly transparent.

The formula for mercury sulphide, HgS, gives the percentage composition: Sulphur 13.8, mercury 86.2 = 100.

If heated on charcoal, a piece of pure cinnabar is volatilized entirely; if anything is left behind, it is only the gangue. In the closed tube it is also sublimed entire, but here it collects again in the cold part of the tube above as a black ring of sulphide of mercury, which has the same composition as the original mineral, for the chemist knows both a black and a red sulphide. In the open tube, if heated very slowly, so as to avoid forming a black ring—in other words, so as to give the sulphur time to oxidize (go off as SO_2)—a ring of metallic mercury is formed in the cold part of the tube (see also p. 148).

Cinnabar is mined at Almaden in Spain, Idria in Carniola, also at New Almaden and other points in California, and less abundantly elsewhere.

COPPER.

Copper is one of the most useful of the metals, having been employed for utensils and in other forms, both as a metal and in different alloys, since very early times. Of recent years its use has been increased very largely because of its good conductivity for electricity. It thus forms the material of the wires of the dynamo machines, those by which the electrical current is carried for the electric light, the trolley, etc. Copper is also extensively used for electroplating, as in making stereotype plates. It forms further a large number of useful alloys, of which brass—an alloy of copper and zinc in the ratio of about 2 : 1—is the best known. In the various kinds of bronze (bell-metal, gun-metal, antique and medal bronze, etc.) copper is also the prominent metal, alloyed with tin; in aluminium bronze it is alloyed with aluminium; in german silver it is alloyed with zinc and nickel.

Copper is obtained in nature in the native state, and also from a variety of valuable ores, which are some of the most interesting and beautiful minerals.

Native Copper, Cu.

NATIVE COPPER is found sometimes in isometric crystals, but they are not often distinct, and the common forms are strings or wires which have a crystalline form but are difficult to decipher (see Figs. 127, 128, p. 61). It is also in grains, plates, and masses, sometimes very large.

The hardness is 2.5 to 3, and the specific gravity 8.8. The luster is metallic and the color that peculiar reddish hue called copper-red. It is highly malleable and ductile, so that it may both be rolled out into sheets and drawn into fine wires. It is an excellent conductor of both heat and electricity. Copper is easily dissolved by nitric acid, giving a blue solution, and ammonia in excess (enough to dissolve the precipitate first formed) turns it a deep azure-blue.

The most celebrated locality for native copper is in the upper peninsula of Michigan on the shores of Lake Superior, where it has been mined for many years. The total production has been very large. Beautiful crystallized specimens have been found here where it is associated with calcite, datolite, and a number of the zeolites. Sometimes it is inclosed in the crystals, as of calcite, so that they are colored bright red from the internal reflections. Great masses of native copper have also been found; one of them weighed 420 tons. Native copper is further found in Arizona, in Siberia, South America, and Australia.

Chalcocite, or Copper Glance. Cuprous sulphide, Cu_2S.

Chalcocite is one of the most valuable ores of copper, for when pure it contains about 80 per cent of the metal. It is found in orthorhombic prisms or pyramids, occasionally having a hexagonal aspect; more commonly in massive forms of a nearly black or bluish-black color. When fresh it has a brilliant metallic luster, which it loses easily, becoming a little dull and tarnished on the surface.

The hardness is 2.5 to 3, and the specific gravity about 5.6. It is brittle when struck with the hammer, but can be cut a little with the knife.

The formula for chalcocite (cuprous sulphide), Cu_2S, gives the composition: Sulphur 20.2, copper 79.8 = 100. On charcoal it is easily reduced by the blowpipe flame alone to metallic copper. Fine specimens come from Cornwall in England (often called redruthite); it was also formerly obtained at Bristol, Conn.

Bornite, or Erubescite. Sulphide of Copper and Iron, Cu_3FeS_3.

Bornite was named after the Austrian mineralogist von Born, but it has a variety of other names—purple copper ore, variegated copper ore, peacock copper, erubescite—all of which suggest a character by which it is easily recognized: the bright iridescent tarnish of the surface.

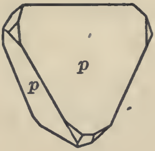
A fresh fracture gives a color of a peculiar reddish bronze and a bright metallic luster, which has led the Cornish miners, a little fancifully, to call it *horse-flesh ore.* This fresh surface soon becomes slightly colored even after a day or two, and gradually the color changes and becomes more variegated, until it is indeed a peacock-copper ore. This character, with the peculiar color of the fresh fracture, makes it always easy to recognize. It is sometimes found in cubic crystals, but usually it is simply massive as imbedded particles or larger pieces. The hardness is 3, and the specific gravity about 5.

Bornite contains both copper and iron, but not always in the same proportions; the formula Cu_3FeS_3 gives: Sulphur 28.1, copper 55.5, iron 16.4 = 100. When heated in the open tube it gives off fumes of sulphur dioxide, which are recognized by the odor and their effect in reddening litmus-paper. On charcoal it fuses to a brittle magnetic globule; after roasting it reacts with borax for iron and copper. It dissolves in nitric acid with separation of sulphur, giving a blue solution.

Chalcopyrite, or Copper Pyrites. Sulphide of Copper and Iron, $CuFeS_2$.

CHALCOPYRITE, or Copper Pyrites, is the beautiful deep brass-yellow copper mineral, often called yellow copper ore. The color is so golden that it is not infrequently mistaken for gold, especially when scattered in small particles through a mass of quartz; but, as we shall see, it can be easily distinguished, though the name "fool's gold," which it shares with the less golden iron pyrites, is still not inappropriate.

165.



It is generally found massive, sometimes in large specimens, sometimes only in specks in the inclosing rock, but it is also found in crystals which commonly are either like octahedrons (though belonging to the tetragonal system), or in wedge-shaped forms called sphenoids (Fig. 165).

The hardness of chalcopyrite is 3.5 to 4, so that, unlike pyrite, it can be easily scratched with a knife. It is brittle, and its specific gravity is a little over 4. The luster is brilliant metallic, and the color, as we have seen, deep brass-yellow; the streak is greenish black. It is often tarnished on the surface, sometimes so as to deepen the color, sometimes variegated so as to rival bornite, with which it might then be confounded, only that the breaking-off of a scale so as to show the color on the fresh fracture serves to distinguish them at once.

It is a sulphide of both copper and iron, and the formula $CuFeS_2$ gives: Sulphur 35.0, copper 34.5, iron 30.5 = 100. Heated on charcoal, a fragment fuses to a black ball which is strongly magnetic, and this roasted with soda gives metallic copper. A fragment in nitric acid dissolves, giving a blue solution which turns azure-blue when ammonia is added in excess.

Chalcopyrite can be easily distinguished from pyrite (iron pyrites) because of its inferior hardness, as noted before; its color, too, is deeper. It is distinguished from gold by its being brittle, breaking into fragments under the point of the knife, while the gold is cut; a particle of gold, too, is not attacked by nitric acid, while the chalcopyrite is easily dissolved with the separation of particles of sulphur. It is a very common mineral, often occurring in veins of quartz with galena and pyrite, though sometimes only as minute specks. When present in large masses, as in Montana, it is one of the valuable ores of copper.

Tetrahedrite, or Gray Copper. Sulphide of Antimony and Copper, $4Cu_2S.Sb_2S_3$.

TETRAHEDRITE is so named because the crystals are commonly tetrahedral in habit (Figs. 166, 167), and often highly modified. Good crystals, as with many of these metallic minerals, are rare and the mineralogist has often to content himself with massive pieces. These he recognizes by the brilliant metallic luster and dark grayish-black color and streak. The hardness is 3–4.5, so that it is easily distinguished from magnetite, which is too hard to be scratched by the knife; the specific gravity varies from 4.4 to 5.1.

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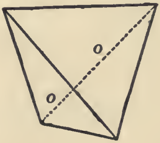

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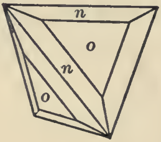


The ordinary tetrahedrite contains sulphur, antimony, and copper, but there are a great many varieties, some of which contain arsenic in place of part of the antimony, and others silver or mercury in place of part of the copper.

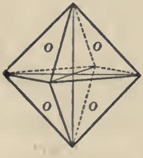
The typical composition is given by the formula $Cu_8Sb_2S_7$ or $4Cu_2S.Sb_2S_3$; this requires: Sulphur 23.1, antimony 24.8, copper 52.1. There is also a related mineral, containing sulphur, arsenic, and copper, which is called tennantite.

In the closed tube tetrahedrite gives a dark red sublimate of antimony oxysulphide; in the open tube sulphurous fumes and a white coating of antimony trioxide. If arsenic is present, it is detected by the odor when the mineral is heated on charcoal; with soda it yields a globule of metallic copper. Cornwall, Bohemia, Hungary, also Colorado, afford fine specimens.

Cuprite, or Red Copper Ore. Cuprous oxide, Cu_2O.

CUPRITE is called red copper because of the fine red color which the clear crystals show, and because of the red color of the streak. The crystals (Figs. 168–170) are often cubes or octahedrons or combinations of them and other forms; sometimes they are highly modified (see Fig. 29, p. 28). In one kind the cubes are spun out into long threads, forming a matted mass of bright red hairs which look very pretty in the cavities of the rock; examined closely with a glass, it is often seen that these threads cross each other at right angles as if trying to build up skeleton cubes, the threads taking the direction of the cubic edges. Common

168.



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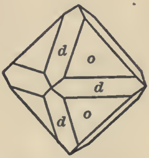

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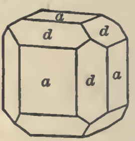


cuprite is a massive mineral, and it is in its cavities that the crystals are usually found.

The hardness of cuprite is 3.5 to 4, and the specific gravity about 6. The luster is adamantine, but on some dark surfaces may look almost metallic; again it is dull and earthy. The color, as remarked above, is bright cochineal-red in the clear transparent crystals, but the surface is often darkened and may appear nearly black. The streak is always brownish red.

The composition of cuprous oxide, Cu_2O, gives: Oxygen 11.2, copper 88.8 = 100. A fragment on charcoal is easily robbed of its oxygen and reduced to metallic copper. Cuprite is not only a beautiful mineral, but also a valuable ore of copper, occurring usually with malachite and other ores, as in Arizona, Cornwall in England, in Australia, etc.

Malachite. Green Carbonate of Copper, $CuCO_3.Cu(OH)_2$.

MALACHITE, the carbonate of copper, is a bright green mineral, often found with native copper, cuprite, and other copper ores because of the readiness with which they are converted into the carbonate by the action of the carbon dioxide present in the air or dissolved in the water.

It may be found in acicular crystals (monoclinic), but only rarely, and the common forms have a rounded or mammillary surface and a concentric fibrous structure (see Figs. 135, 136, p. 68). When close and compact it can be cut and polished and thus form a handsome ornamental stone. The malachite of Siberia is used in this way, table-tops, vases, and columns having often been veneered with it.

The hardness is 3.5 to 4, and the specific gravity about 4. The color is a bright green; the streak a little paler; it is transparent only in minute crystals.

The formula of malachite is $CuCO_3.Cu(OH)_2$ or $2CuO, CO_2.H_2O$, which gives: Carbon dioxide (CO_2) 19.9, cupric oxide (CuO) 71.9, water (H_2O) 8.2 = 100. A fragment heated in the forceps gives a green flame characteristic of copper, and in the borax bead the reactions described on pp. 136, 137. It yields a good deal of water in the closed tube, and in nitric acid dissolves with the effervescence of carbon dioxide. Malachite is found in fine specimens at many localities, as in the Siberian mines, in Cornwall, Australia, and Arizona.

Azurite, Blue Carbonate of Copper. $2CuCO_3.Cu(OH)_2$.

AZURITE, or the Blue Carbonate of Copper, is not so common as malachite, but it is also a beautiful mineral, and when in large transparent crystals of a fine deep blue it forms one of the most attractive specimens in a cabinet. The crystals are oblique rhombic prisms. The hardness is 3.5 to 4, and the specific gravity is 3.8. The luster is vitreous, the color azure-blue, and the streak somewhat lighter.

The composition is expressed by the formula $2CuCO_3.Cu(OH)_2$ or $3CuO.2CO_2.H_2O$; this gives: Carbon dioxide (CO_2) 25.6, cupric oxide (CuO) 69.2, water (H_2O) 5.2 = 100. It hence differs from malachite in containing less water; it is not uncommon to find crystals which are blue on the outside but have changed within to a fibrous mass of green malachite. The most famous localities are those of Chessy, near Lyons in France, and the Copper Queen mines and elsewhere in Arizona.

Dioptase, or Emerald Copper, the silicate of copper, has a beautiful emerald-green color. It is a rare mineral, only known to occur at a few localities, one of which is in Asia, another in Arizona, another in the French Congo region in Africa. The crystals are commonly hexagonal prisms with rhombohedral faces on the ends. The formula is $H_2O.CuO.SiO_2$, which gives : Silica 38.2, cupric oxide 50.4, water 11.4 = 100.

Chrysocolla is another silicate of copper of a bluish-green or sky-blue color. It occurs in massive forms sometimes earthy, also looking a little like malachite. The hardness is 2 to 4; the specific gravity 2.2. It contains a good deal of water, which it gives off in the closed tube. The formula is $CuSiO_3.2H_2O$. It is a not uncommon product of the alteration of other copper minerals.

There are many more copper minerals, most of them too rare to be described here. They include a number of hydrous sulphates, of which the most important is chalcanthite or blue vitriol, a common substance at the druggist's and often to be seen in clusters of large crystals, but rare in nature. The sulphate, brochantite, may also be mentioned. There are further several arsenates of copper, including olivenite ; several phosphates, including libethenite; several chlorides, as atacamite; and so on.

LEAD.

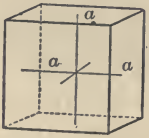
Lead is one of the most important of the metals, used for many purposes familiar to all, as for pipes, to convey water, for shot and rifle-balls, etc. It has a dull blue-gray color. It is very soft and malleable, and fuses readily at a comparatively low temperature (see p. 132.) It is often alloyed with other metals; thus with tin in common solder and pewter; with antimony in type-metal; with arsenic in small amount for making shot. White lead (the carbonate) is largely used in making paint, also the oxide, red lead.

NATIVE LEAD is a very rare mineral, though occasionally found in small amount, particularly in Sweden. The supply of the metal, which is used so largely in the arts, is obtained from its ores, especially the sulphide, galena. Other important lead minerals are the phosphate, pyromorphite; the sulphate, anglesite; the carbonate, cerussite.

Galena. Lead sulphide, PbS.

GALENA crystallizes in the isometric system, and occurs commonly in cubes; it is also found in octahedrons and very frequently in combinations of these two forms as, too, of other forms of this system (Figs. 171–173, also Fig. 20, p. 25). It has very perfect cubic cleavage, and a mass often breaks up into a multitude of little rectangular blocks (see Fig. 143, p. 71). This cubic cleavage is readily seen in the common coarse-granular kinds, and is revealed also by the spangling of the surface in those which are fine-granular.

171.



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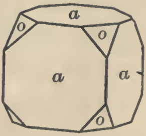

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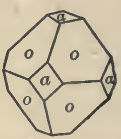


The hardness is 2.5, and the specific gravity is 7.5 or nearly as high as metallic iron, for lead being a metal of high density (G. = 11.4), all its compounds have the same property.

The luster is metallic and usually very brilliant; the color is a bluish lead-gray, but the exposed surface of a specimen is often somewhat dull from tarnish.

Galena is lead sulphide, PbS, which gives the percentage composition: Sulphur 13.4, lead 86.6 = 100. On charcoal a fragment fuses easily, yielding finally a globule of metallic lead and a yellow coating of lead oxide near it and a white coating at a distance from it (see p. 144). With soda on charcoal metallic lead is readily obtained.

Galena is the most important ore of lead and one of the commonest of minerals, occurring in large deposits in many mining regions; for example, in Missouri, Illinois, Iowa, and Wisconsin; also in Colorado and abroad in Derbyshire, England; Freiberg, the Harz, and so on. It also occurs, but less abundantly, with the ores of other metals. Sphalerite, calamine, smithsonite, also pyrite and chalcopyrite are common accompanying metallic minerals; quartz, calcite, barite, also fluorite, are common non-metallic minerals associated with it and then called the gangue. As resulting from its own decomposition, lead carbonate (cerussite) and also lead sulphate (anglesite) are often found with galena; less often pyromorphite and other lead minerals. Much galena carries a small amount of silver, and when this is sufficient in quantity to justify its being worked for the precious metal, it is regarded as a silver ore and called *argentiferous galena.*

Galena is used not only as a source of lead or sometimes of silver, but also for glazing common stoneware; it is hence called *potter's ore.*

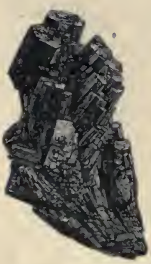
JAMESONITE is a rare sulphide of lead and antimony ($2PbS.Sb_2S_3$) occurring in acicular crystals, also in fibrous or compact masses. Hardness 2 to 3; specific gravity 5.5 to 6. The luster is metallic and the color is steel-gray to dark lead-gray ; it resembles stibnite both in form and color.

BOURNONITE is another rather rare sulphide of lead and antimony containing also copper ($3(Pb,Cu)S.Sb_2S_3$). It occurs in short prismatic or tabular crystals, often grouped in wheel-shaped forms ; also massive and compact. Hardness 2.5 to 3 ; specific gravity 5.7 to 5.9 ; luster metallic; color dark steel-gray, inclining to iron-black.

Pyromorphite. Lead phosphate, $3Pb_3P_2O_8.PbCl_2$.

PYROMORPHITE is found in small hexagonal prisms which are sometimes cavernous in form, also often rounded into barrel-shaped forms, or even nearly spherical. The crystals are frequently clustered together in a curious way, branching out from a slender stem, as shown in Fig. 174. It also occurs as a thin crust or coating, which may be drusy on the surface, or simply globular or mammillary.

174.



Pyromorphite has a hardness of 3.5 to 4, and, like all compounds of lead, a high specific gravity, viz., 6.5 to 7. The luster is resinous and the color is commonly green, varying from grass-green to both darker and lighter shades; it is also sometimes pale brown. The streak is not far from white even in the deep green varieties.

It consists essentially of phosphate of lead, $Pb_3(PO_4)_2$, but contains also some chlorine. Hence when heated in the tube a little lead chloride is driven off and forms a white coating above. The same white coating is also deposited on charcoal at a distance from the fragment which is being heated; more conspicuous than this is the yellow coating of lead oxide (PbO) which is formed just about the fused fragment. Also if the fragment, after it is completely fused, is examined, it will be seen that it is nearly spherical, has a brilliant luster, and sparkles on the surface from the reflection of light from a multitude of crystalline facets; it is this that gives the name to the mineral from the Greek words meaning *fire* and *form* (*πῦρ* and *μορφή*). The fused globule, if heated further on charcoal with the addition of some sodium carbonate, yields globules of metallic lead.

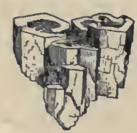
MIMETITE and VANADINITE are two ores of lead which are closely related in form and composition to pyromorphite.

Mimetite consists essentially of lead arsenate, and *vanadinite* of lead vanadate, and each, like pyromorphite, also contains a little chlorine. Certain intermediate varieties contain both arsenic and vanadium.

Mimetite is usually yellow in color and has a resinous luster; it sometimes closely resembles pyromorphite in form (hence the name from *μιμητής*, *imitator*), but distinct crystals are more rare and rounded indistinct forms the rule. The hardness is 3.5, and the specific gravity 7 to 7.25. It is easily recognized by yielding arsenical fumes on charcoal with their peculiar odor, while the reactions for lead are the same as for pyromorphite.

Vanadinite is often of a beautiful deep red color, and when the crystals are clear and sharp it is one of the most beautiful of minerals, especially in the forms found of late years in some of the mining regions of Arizona; less brilliant yellow and light brown varieties also occur. The crystals are hexagonal prisms, often terminated by several hexagonal pyramids; cavernous forms also occur as with pyromorphite (Fig. 175). The hardness is about 3, the specific gravity 6.7 to 7. The luster is resinous.

175.



The reactions for lead on charcoal are like those of pyromorphite; the vanadium is recognized by the yellow and emerald-green colors which it gives to the salt of phosphorus bead, the former in the oxidizing, the latter in the reducing flame (see p. 139).

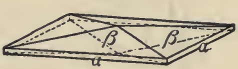
It may be interesting to add that the rare element vanadium, present in vanadinite and some of the vanadates (as descloizite, a vanadate of lead, zinc, and copper), has found a use in the arts in calico-printing; it is also used for vanadium black, in making ink, and to fix the colors in the manufacture of silk.

Somewhat resembling vanadinite in bright color are two rather rare lead minerals, Crocoite or lead chromate, $PbCrO_4$, and Wulfenite or lead molybdate, $PbMoO_4$.

Crocoite occurs in oblique prismatic crystals (monoclinic) of a fine orange-red color and giving a deep yellow streak. The hardness is 2.5 to 3, and the specific gravity about 6. The luster is adamantine to vitreous. It is recognized by the lead coating which it gives on charcoal, and by the reactions for chromium, which yields a green bead with borax in both the oxidizing and reducing flames (see p. 138).

Wulfenite is not so rare as crocoite, and is one of the many fine minerals which the western mining States have afforded in great variety and beauty, where it often occurs with vanadinite. It is found in square crystals (Fig. 176) or tables frequently as thin as a knife-edge and perfectly clear; also in square pyramids, sometimes low and less often acute. The color is a bright orange-yellow to reddish yellow, or again brown or green; the luster is resinous or adamantine. The hardness is about 3, and the specific gravity 6.7 to 7. The square form and bright color make it usually easy to recognize it.

176.



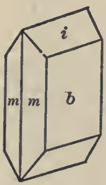
With the blowpipe on charcoal it gives a lead coating, and with soda metallic lead. With salt of phosphorus it gives the reactions for molybdenum (p. 139).

Cerussite, or White-lead Ore. Lead carbonate, $PbCO_3$.

Cerussite, the carbonate of lead, is the commonest ore of lead next to galena, and with this it commonly occurs for the simple reason that in nature's laboratory, where carbon dioxide (CO_2) is often present, the sulphide of lead (PbS) is often changed into the carbonate ($PbCO_3$). This is a good illustration of what mineralogists call the association of minerals, often a very important guide as to their nature. It is in the same way, as has been stated, that the carbonate of copper (malachite) often occurs with the sulphides, the oxides, etc.

The clear and colorless, or perhaps white or slightly yellow, crystals of cerussite do not perhaps at first suggest to the eye that it is a mineral containing the metal lead. A more careful examination, however, shows the adamantine luster, and this, as has been stated (p. 89), belongs to crystals which refract the light largely, in general either because they are very hard (as the diamond), or because they contain heavy atoms, as those of lead. It is a good thing to remember that all the compounds of lead have an adamantine or a resinous luster, and the same is true of the kind of glass containing much lead called paste, out of which imitation jewels are made.

177.



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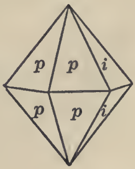

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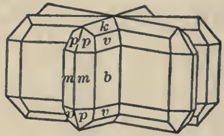


The crystals of cerussite are sometimes thin plates (Fig. 177), with sides covered with fine horizontal lines; but rhombic prisms and pyramids also occur; Fig. 178 resembles a hexagonal pyramid in form and angle. This is one of the species which is frequently in twins, and six-rayed starlike forms, in which the branches cross at angles of 60° and 120°, are common (Fig. 179, also Fig. 120, p. 58).

The hardness is only 3 to 3.5, and the specific gravity is high, about 6.5, as must be true of a compound of lead; this last character is one that should be noticed first if a mass approximately compact is in the hand. Sometimes, however, the mass of crystals is so open and porous that the effect of high density is lost.

The composition, lead carbonate, $PbCO_3$, gives: Carbon dioxide (CO_2) 16.5, lead oxide (PbO) 83.5 = 100. Heated on charcoal carefully (for it decrepitates at first) a fragment is easily fused and soon yields a globule of metallic lead, while about it the familiar lead coating is formed. Placed in a test-tube with a little nitric acid, the carbon dioxide (CO_2) is given off with effervescence. This species is common in Colorado and other mining regions; it is valuable as an ore of lead and often of silver. It is the same as the artificial white lead used for paint.

Anglesite. Lead sulphate, $PbSO_4$.

ANGLESITE resembles cerussite, and like it is frequently found in cavities in the sulphide, galena (PbS), from which it is formed by oxidation. It is often in crystals, which are either rhombic prisms or pyramids, and sometimes very highly modified; the crystals resemble barite in form and angles (see p. 262). Cleavage exists parallel to the prism and the base, but it is interrupted. It is also found in closely compact forms which are not so easy to recognize, but whose high specific gravity is suggestive.

The hardness of anglesite is 2.75 to 3, and the specific gravity 6.2 to 6.4. The luster is adamantine in most cases, especially on a fracture surface, sometimes varying to resinous. The crystals are usually clear and colorless, but the masses may be brown and nearly opaque.

The formula for lead sulphate, $PbSO_4$, gives: Sulphur trioxide (SO_3) 26.4, lead protoxide (PbO) 73.6 = 100. On charcoal before the blowpipe it decrepitates and fuses readily to a clear bead, which becomes milk-white on cooling; in the reducing flame it yields metallic lead. With soda on charcoal lead is easily obtained, and the soda reacts for sulphur as explained on p. 146. It dissolves with difficulty in nitric acid, and does not effervesce as does cerussite, and hence the two are easily distinguished in this way. Beautiful crystals come from Anglesea (whence the name), from Sardinia, from Phœnixville, Penn. It occurs in large quantities in Mexico and Australia.

TIN.

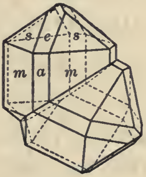
TIN, one of the most important of metals for a great variety of technical purposes, occurs, if at all, only very rarely in nature in the native metallic state. The supply is obtained almost solely from a single ore, the mineral cassiterite, or tin-stone. There is also a rare sulphide of tin, copper, and iron, called STANNITE. The use of tin that first suggests itself is for *tin plate*, so largely employed for vessels, roofing, etc; this is simply sheet iron coated with metallic tin. Tin enters into many alloys, as the various forms of bronze (gun-metal and bell-metal, etc.) in which it is alloyed with copper; it also forms alloys with lead in pewter and several kinds of solder; with antimony in Britannia metal; with both lead and antimony in

Queen's metal, and copper and antimony in Babbitt metal; with lead and bismuth in fusible metal (see p. 178).

Cassiterite, or Tin-stone. Tin dioxide, SnO_2.

Cassiterite, or tin-stone, occurs, when crystallized, in square prisms and pyramids and other related forms; twin crystals are common (Fig. 180). The crystals have a splendent adamantine luster and a brown color, sometimes nearly black. It is also found disseminated in irregular particles in certain rocks, and there is a kind called *stream-tin*, which consists of rolled grains or pebbles of the mineral; the massive forms sometimes have a botryoidal or reniform surface, a fibrous structure (then called *wood-tin*), a brownish color, and a dull luster.

180.



Cassiterite is remarkable for its hardness (6.5 to 7), and still more for its high specific gravity, about 7. The composition is tin dioxide, SnO_2, which when pure contains 78.6 per cent of metallic tin.

Cassiterite occurs commonly in granite; either in veins or sprinkled through the rock, often in inconspicuous particles, which can be separated by the same process that nature has used in making stream-tin, that is, after the rock has been crushed, by washing away the lighter material by running water, the heavy tin-stone, more or less pure, being left behind.

Cassiterite is rather easily recognized when in large crystals or masses by its high specific gravity, hardness, rich brown color, and brilliant luster. But confirmation is usually needed, and this can be gained by grinding some of the mineral fine in an agate mortar, mixing it with sodium carbonate, and patiently roasting it on charcoal. After a little time small globules of a white metal separate, and by the method described on pp. 145, 146 they can be shown to be malleable under the hammer, while they are harder than silver, which they resemble; in nitric acid they are oxidized to an insoluble white powder, having the same composition as the original mineral.

Cassiterite is found sparingly at a number of points in the United States, but attempts to mine it, as near Harney's Peak, S. Dakota, and in San Bernardino County, California, have not been successful. It is obtained in Mexico rather abundantly in the state of Durango. The Cornwall mines in England have furnished it for many centuries, as also the Saxon and Bohemian mines. Borneo, Sumatra, Banca, Malacca, and other islands in the East Indies, and further, Australia, yield large quantities at the present time.

TITANIUM.

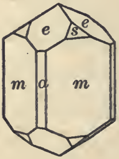
Titanium is a rare element, chemically related to tin; it is of no special economic importance at present, though it forms certain alloys which may come into use in the future. The most important minerals containing titanium are the oxides rutile, octahedrite, brookite; also the silico-titanate, called titanite or sphene; the last-mentioned mineral is described on a later page. Rutile, octahedrite, and brookite have all the same composition, namely, titanium dioxide, TiO_2, but they differ in crystalline form.

Rutile is tetragonal, and Octahedrite (see Figs. 43, 45,

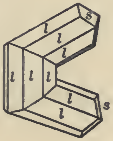
p. 32) is also, but of different form, while **Brookite** belongs to the orthorhombic system. The last two species are so rare that they will not be particularly described, but rutile, though not common, is more important.

One form of the crystals of rutile is shown in Fig. 181; others are twin crystals, sometimes quite complex, eight partial crystals occasionally going together to make one compound group. Other twins are of the knee-shaped kind, called geniculated, as shown in Fig. 182.

181.



182.



The hardness is 6 to 6.5, and the specific gravity about 4.2. The color varies from reddish brown to red or yellowish, and also to nearly black, though even in the last variety thin splinters let through a little reddish light. The luster is usually metallic-adamantine. It is quite infusible and reacts for titanium (see p. 139), and also most varieties for iron, which is usually present (3 to 4 p. c. Fe_2O_3).

Rutile is found chiefly in gneiss or granite, also in granular limestone. It is occasionally cut for mourning jewelry. When penetrating rock-crystal in very slender transparent crystals it forms specimens of great beauty, particularly when polished; these are sometimes called love's arrows or *flêches d'amour*. Rutile is also used to color porcelain yellow and to give a tint to artificial teeth.

URANIUM.

URANIUM is another rare element, but one of some importance economically. Its compounds have usually a bright yellow or green color, and a little present in glass gives it a bright canary-yellow of fluorescent properties. It is employed in certain pigments; also in painting on porcelain.

The most important mineral containing uranium is URANINITE, in which it is combined with oxygen; some lead and other rare elements are also present. It occurs rarely in black octahedrons of very high specific gravity, up to 9.7, also commonly in massive forms having a pitch-black color and luster, and hence called *pitchblende*. This last variety is more or less altered and yields some water in the closed tube.

Two other uranium minerals are TORBERNITE, phosphate of uranium and copper, a mineral of a bright green color, and AUTUNITE, phosphate of uranium and calcium, which is bright yellow. Both minerals occur in thin tabular crystals which have a basal cleavage, somewhat resembling mica (though the scales are brittle), and hence they are sometimes included together under the name of *uranium mica*.

IRON.

IRON may well be called the most important of all the metals. How large a place it takes in the work of the world is shown by the fact that each year some 50 million or more tons are produced from its various ores and turned into some of the many forms needed by man in his work. Its manifold uses are too well known to need enumeration here. The entire supply of iron which the world uses each year is obtained from its ores, in which the iron is in combination chiefly with oxygen. These ores are the minerals hematite, magnetite, and limonite; siderite, the carbonate of iron, is also an important ore.

These ores smelted, for example with limestone as a flux, in a blast-furnace with charcoal or coke, yield *pig iron*, an impure form containing much carbon. This is also sometimes called *cast iron*,* though now this name is chiefly given to iron, remelted in a cupola furnace and cast in any desired form, which is also rich in carbon. If purified so as to contain but little carbon, it becomes *wrought iron* of very different properties, while *steel* is in composition intermediate between the two forms mentioned. Steel is now obtained chiefly by the Bessemer process. It is remarkable because of its great strength and the varying degrees of hardness and elasticity which can at will be given to it by the process called tempering.

NATIVE IRON, or iron occurring in nature in the metallic condition, is only known as a great rarity and hence is of no practical importance. The meteorites (p. 2) which occasionally fall to the earth often consist entirely of metallic iron, while others that have a stony aspect contain many particles of metallic iron distributed through the mass. Native iron has also been noted a few times in terrestrial rocks, but only one occurrence is especially noteworthy—that of Disko, Greenland, where it has been found in large masses imbedded in basalt.

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* Cast iron is hard, brittle, fusible, and not weldable; wrought iron is soft, malleable and ductile, weldable and fusible at a high temperature; steel is malleable, weldable and fusible, with a varying hardness depending upon the temper. (*Cent. Dict.*)

Pyrrhotite, or Magnetic Pyrites. Iron sulphide, Fe_7S_8.

PYRRHOTITE takes its name from a Greek word meaning reddish (πυῤῥότης) because of its peculiar reddish bronze color; this is a very important character to remember. The common name, *magnetic pyrites*, refers to its still more striking character of being magnetic and hence attracted by a magnet.

Pyrrhotite is rarely found in hexagonal crystals, but for the most part it occurs in irregular masses. The hardness is 3.5 to 4.5, and the specific gravity 4.6. The luster is metallic, and the color, as before noted, a peculiar reddish bronze quite different from the other kinds of iron pyrites; the streak is dark grayish black.

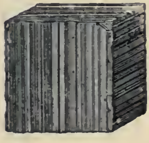
It is a sulphide of iron nearly equivalent to the simple sulphide, FeS, though never having exactly this composition; on the contrary the common formula is Fe_7S_8. On charcoal it fuses to a magnetic globule, and in the open tube gives sulphurous fumes. It is decomposed by hydrochloric acid with the separation of the ill-smelling gas hydrogen sulphide.

Pyrrhotite often contains nickel, and though it is not usually present in large amount (rarely over 5 per cent), this species occurs so abundantly, for example at Sudbury, Ont., as to constitute one of the most important ores of nickel.

Pyrite, or Iron Pyrites. Iron disulphide, FeS_2.

PYRITE is one of the commonest and most striking of metallic minerals. It is often found in cubic crystals (Fig. 183), and the faces of these usually show, if carefully examined, fine lines or striations parallel in each case to one pair of edges only; further, on each face the direction is at right angles to those on the adjoining faces. These striations have been explained before (p. 52) as due to what is called oscillatory combination of the cubic faces with those of the pyritohedron. Octahedrons of pyrite are also common, and the twelve-sided form called from this species a *pyritohedron* (Fig. 184). These last sometimes show fine striations like the cube, and often the two forms are both present and sometimes they are rounded together. Fig. 185 shows the pyritohedron and cube; Figs. 186, 187, the pyritohedron and octahedron. The angle between *a* and *e* is 153° 26′; between *o* and *e* 140° 46′. Pyrite is also found in massive form and sometimes in large beds which can be mined for the sake of the sulphur which the ore yields on roasting.

183.



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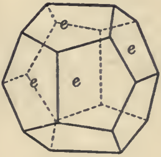

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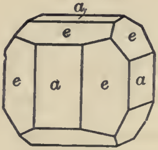

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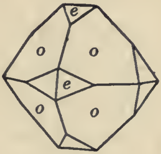

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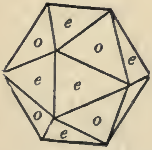


The hardness of pyrite is a little above 6, so that it scratches glass and is not scratched by an ordinary knife. It is thus unusually hard for a sulphide, and it is due to this that it strikes fire with the steel, which is the source of the name pyrites, which it shares with some other hard sulphides (see the Index). The specific gravity is 5. The luster is brilliant, metallic, and the color light brass-yellow, sometimes growing a little deeper when tarnished. The streak is dark greenish black.

The composition is iron disulphide, FeS_2, which gives: Sulphur 53.4, iron 46.6 = 100. Though consisting nearly one half of iron, it is of no value as an iron ore, but it is employed for making sulphur and sulphuric acid; some kinds (called *auriferous pyrites*) are mined for the small amount of gold they yield when smelted. It fuses on charcoal to a black metallic bead, giving off sulphur which burns and produces the suffocating fumes of sulphur dioxide; in the closed tube the sulphur which is driven off collects in the cooler part of the tube in a liquid ring which is orange-red when hot and turns sulphur-yellow as it grows cool and solidifies.

Pyrite is, as has been stated, a very common mineral, forming large beds, as in Spain, at Rowe, Mass., and in Virginia. In metallic veins it is almost always present, sometimes abundantly. It is also often found in crystals in slates and many kinds of rocks, and in coal, though then much diminishing its value if in large amount.

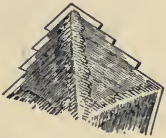
Pyrite is often associated with chalcopyrite, or copper pyrites, but, as stated on p. 192, it is easy to distinguish the two minerals by the difference in hardness and color, also by blowpipe characters.

Marcasite, or White Iron Pyrites. Iron disulphide, FeS_2.

MARCASITE has the same chemical composition as the more common kind of iron pyrites, called pyrite, but it differs in the form of the crystals, in specific gravity, somewhat in color, and other respects. The two are consequently distinct minerals, and the compound FeS_2 is said to be *dimorphous* (p. 120).

Marcasite crystallizes in orthorhombic prisms and pyramids, which it is generally easy to distinguish from the cubes and pyritohedrons of pyrite. The crystals are often compounded together and grouped in various forms, to which some fanciful names have been given, as *spear pyrites* (Fig. 188), *cockscomb pyrites*, etc. It often forms nodules, spherical forms, or stalactites, and is also simple massive.

188.



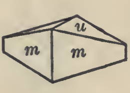
The hardness is 6 to 6.5, or the same as pyrite, but the specific gravity is lower, only 4.8 instead of 5. The color, too, is a paler yellow when quite fresh, so that it is often called *white iron pyrites*. It is, however, more easily altered by the action of the weather and becomes tarnished, the metallic luster then becomes dull, and the true color is more or less obscured.

Arsenopyrite, or Arsenical Pyrites. Iron sulph-arsenide, $FeS_2.FeAs_2$.

ARSENOPYRITE is another member of the pyrites group, and like the others is hard enough to strike fire with a steel. It is near to pyrite and marcasite in composition, but besides sulphur contains also arsenic, so that it is often called arsenical pyrites; mispickel is another name. It is found commonly in masses, but occurs also in orthorhombic crystals, which are much like those of marcasite and sometimes twinned in the same way. The angle between the front *m* faces is 112°, and of *e* (over the top edge) 59½°, of *u* 147°, of *q* 80°.

The hardness is about 6, and the specific gravity also 6. The luster is metallic, and the color when fresh silver-white, becoming a little dull and tarnished after exposure. The color is, therefore, quite different from the reddish bronze of pyrrhotite or the pale yellow of pyrite and marcasite. The streak is grayish black.

189.



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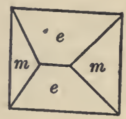
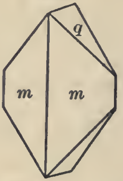


191.



The formula is FeAsS, which, to show the relation to marcasite, may be written $FeS_2.FeAs_2$. This gives the following percentage composition: Sulphur 19.7, arsenic 46.0, iron 34.3 = 100. Heated alone on charcoal it fuses to a black magnetic globule, giving off dense white fumes of arsenic trioxide, As_2O_3, which are so volatile that they do not condense on the coal except at a considerable distance from the flame. The touch of a flame upon this white coating drives it away. In the open tube, heated *very slowly*, the sulphur is oxidized and passes out of the tube as SO_2, and the arsenic forms As_2O_3. which condenses in t tube as brilliant spangling octahedral crystals—this is the poisonous "white arsenic" (or simply "arsenic") of the druggist, and it is obtained in large quantities in the process of roasting this mineral as well as arsenical ores of iron and cobalt, as in Cornwall. Heated in the closed tube, where there is no air supplied, a dark red ring of arsenic sulphide (As_2S_3) is first formed; if the heating is continued, metallic arsenic now goes off, and collects as another ring, which is in black and lustrous scales. The arsenopyrite of Deloro, Canada, is auriferous and hence mined for the gold it yields.

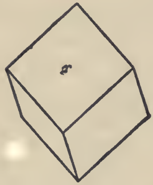
*__Hematite,__ or Red Oxide of Iron. Iron sesquioxide, Fe_2O_3. *

HEMATITE is named from the Greek word for blood (*αἷμα*), because many kinds show a red color and all varieties give a red streak. It is found in a great many different forms and is a difficult mineral, consequently, for the beginner to learn thoroughly. The kinds with a brilliant metallic luster are called *specular iron;* beautiful specimens of this come from the island of Elba, where it is found in thick rhombohedral crystals with brightly polished faces, often with a beautiful iridescent tarnish on the surface. These crystals are usually rather complex (Figs. 194, 195), but occasionally the simple form resembling a cube in angle (86°) is observed (Figs. 192, 193). Other crystallized kinds, perhaps more common, are in thin plates or scales (Figs. 196, 197), sometimes so thin as to be transparent, and blood-red in color when looked through. The specular iron is also massive, with black color and brilliant luster, and the masses have sometimes a peculiar smooth, almost conchoidal, fracture; certain forms have a reniform surface.

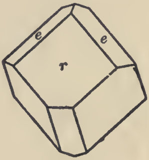
Other kinds of hematite are in scales a little like mica, sometimes black and shining, less often soft and reddish and soapy to the feel; also in minute pealike forms, called fossil ore. An earthy kind, dull in luster, is the *red ocher*, used for making paint.

The hardness of most kinds of hematite is about 6, so that it is too hard to be scratched by the knife; but some of the scaly kinds are soft and unctuous to the touch. The specific gravity of the crystals is 5.2. The luster is metallic in the specular iron variety, but dull and earthy in others. The color is usually iron-black, but also red. The streak is a dull red, a little like that of dried blood; the black micaceous kinds have to be ground quite fine to show this. Some kinds are slightly magnetic, but probably only because of a small admixture of magnetite.

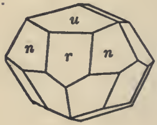
192.



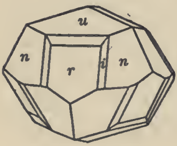
193.



194.



195.



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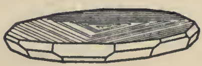
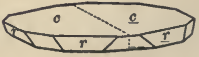


197.

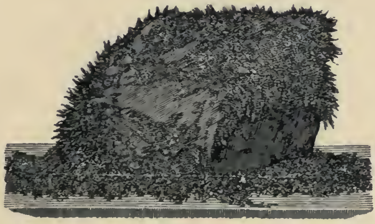


Hematite is the sesquioxide of iron, Fe_2O_3, and if pure contains 70 per cent of metallic iron; it is also called ferric oxide by the chemist, in distinction from the protoxide or ferrous oxide, FeO. Heated in the reducing flame of the blowpipe, a fragment is partially converted into the magnetic oxide so that a magnet will pick it up. Hematite is the iron ore mined in much of the Lake Superior region, at Birmingham, Alabama, and elsewhere in the Southern States, and formerly at the famous Iron Mountain of Missouri. The most beautiful crystallized specimens have come from the island of Elba; Switzerland and France also afford fine crystals.

Magnetite or Magnetic Oxide of Iron. $Fe(Fe_2)O_4$.

MAGNETITE suggests in its name its most striking character, that of being *magnetic.* All kinds are strongly attracted by a magnet, and one variety, called the *lodestone,* found for example at Magnet Cove, Arkansas, is a powerful magnet itself. It has a north and south pole, the power of picking up particles of iron or steel, as tacks, and also, when suspended, it sets with its poles north and south like a compass-needle.

198.

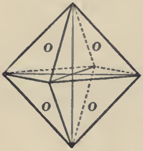


Lodestone.

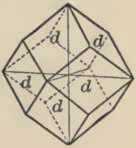
Magnetite is found in octahedral or dodecahedral crystals (Figs. 199–201); more commonly simply massive, and then sometimes with a peculiar fracture, suggesting cleavage, yielding octahedral fragments.

The hardness is high, about 6, like that of hematite, and the specific gravity is nearly the same, 5.18. The luster is metallic, usually very brilliant, and the color iron-black. The streak also is black, and this is a most important character, for it distinguishes it at once from hematite, which, though at times iron-black in the mass, has a *red* streak.

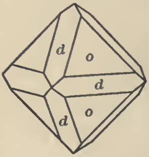
199.



200.



201.



The composition is expressed by the formula $Fe(Fe_2)O_4$ or $FeO.Fe_2O_3$, which is equivalent to Fe_3O_4, yielding 72.4 per cent of metallic iron. It is fused with great difficulty, but a small fragment heated carefully in the oxidizing flame loses part if not all of its magnetic property. It is soluble in hydrochloric acid.

Magnetite, like hematite, is a very important ore of iron. It has been mined in the Adirondack region, as at Port Henry, in large quantities and elsewhere; also in the West Point region; at Brewster, Putnam County; in New Jersey. It also occurs in the Lake Superior region, where, however, the commoner ore is hematite. The famous Swedish iron and steel are made from magnetite. Besides these great deposits magnetite is a common mineral in many rocks, occurring in little particles distributed through the mass. It is thus prominent in the trap rocks of Connecticut, Massachusetts, and the Palisades of the Hudson. When the rocks containing magnetite are broken up by the weather and reduced to the condition of sand and gravel, the magnetic iron, being heavier, is often sorted out by the water and accumulated by itself; a stream by the side of a country road often shows a streak of the black iron sand, and at the seashore it may be found in quite large quantities. It has been mined in this way at Block Island, being separated by a large magnet from the associated sand and gravel.

Franklinite, so called from its sole locality, Franklin Furnace, New Jersey, is a mineral in form, color, and general appearance much resembling magnetite, but it is only feebly magnetic if at all, and has a brown, not black, streak. It is an oxide containing besides iron also zinc and manganese, and is hence valuable as a zinc ore and for making spiegeleisen, an alloy of iron and manganese employed in the making of steel.

Chromite, or Chromic Iron, is another iron ore looking much like magnetite, also crystallizing in octahedrons, though the massive form is the common one. It contains chromium besides iron, and with borax yields a chrome-green bead (p. 138). It is not a particularly interesting mineral and is of limited occurrence, but valuable as a source of the element chromium, which forms a bright-colored (usually yellow or green) class of salts called *chromates;* these are used for pigments and in calico-printing. Chromium is also used in chrome-steel. It is often associated with serpentine, as in Pennsylvania and Maryland; it is also mined in California and in Turkey.

ILMENITE, or titanic iron, is related to hematite and magnetite, but differs from the former in having a black streak, and from the latter in not being magnetic. It contains titanium besides iron and oxygen, and the formula of some kinds is $FeTiO_4$. Like magnetite it occurs in minute particles in certain rocks and it also forms beds of some magnitude. Part of the magnetite contains titanium (or is titaniferous) and is then of much less value as an ore because highly refractory, or hard to reduce in a furnace.

Limonite, Brown Oxide of Iron. $2Fe_2O_3.3H_2O$.

LIMONITE is a hydrous oxide of iron, that is, it contains some 14 per cent of water which it gives off when heated. It is often called *brown hematite*, because while resembling some kinds of hematite it has usually a brown color and always a brown streak. It is not known in crystallized forms, but occurs only massive, especially in stalactitic shapes, or forms with rounded surface (see Fig. 140, p. 68). Its structure is frequently fibrous, but earthy in the *brown ocher* used for paint.

The hardness in the compact kinds is about 5, or less than that of hematite and magnetite, and the specific gravity is a little below 4. The luster varies from submetallic to earthy; it is sometimes brilliant on the glossy surfaces of stalactites, but more commonly dull.

It is a hydrated oxide, $2Fe_2O_3.3H_2O$, and only contains 60 p. c. of metallic iron if perfectly pure, which is rarely the case. Heated in the closed tube considerable water is given off which condenses in the colder part of the tube; the fragment after heating turns red and has a red streak; —by the loss of water it has been converted into anhydrous iron sesquioxide, Fe_2O_3, or hematite.

Limonite is named from the Greek word (λειμών) meaning *meadow*, because often found in marshy places; in fact one kind is also called bog iron ore. It is mined in many deposits in western New England and adjacent parts of New York, also in Pennsylvania, Virginia, etc. It is a low-grade ore, that is, it yields only a relatively small amount of iron because of the clay and other impurities present.

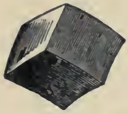
GOETHITE, named after the poet Goethe, is another oxide of iron yielding water. It occurs in brilliant prismatic crystals and also in massive forms, often fibrous in structure. It has a yellow-brown to deep brownish-black color and a streak like that of limonite, which it also resembles in some of its forms. It is of limited occurrence.

TURGITE is still another iron hydrate, not common; it occurs in forms like limonite, but yields only 5 per cent of water and has a red streak; it usually decrepitates when heated before the blowpipe.

Siderite, or Spathic Iron. Iron carbonate, $FeCO_3$. *

SIDERITE, the carbonate of iron, is also an important ore, although less so than the three prominent oxides. It crystallizes in rhombohedrons, often with rounded faces (Fig. 202), and has perfect rhombohedral cleavage. This cleavage is a very prominent character in the common massive kinds; the angle between two adjacent cleavage surfaces is 107° or 73°; it is the same form that we shall learn with calcite; indeed, as explained on p. 119, the two species form with several others an isomorphous group. The hardness is 3.5 to 4, and the specific gravity is rather high, 3.8; this instantly suggests to one picking up a specimen that a heavy metal is present. The luster is vitreous and the color light yellow to brown, becoming dark by alteration; the streak is white or nearly so.

202.



It is a carbonate of iron, $FeCO_3$, and contains 48 per cent of metallic iron if pure. In acid, if slightly warmed, it dissolves with effervescence, giving off carbon dioxide gas; before the blowpipe it turns black, fuses, but not very easily, and becomes magnetic. It is largely mined in Cornwall, and is also found in Pennsylvania, Ohio, etc.

Columbite is a rare iron mineral, occasionally found in jet-black crystals or masses in the granite veins of New England; it resembles tourmaline somewhat, but is much denser, having a specific gravity varying from 5.4 to 6 or over. Its luster is submetallic. A figure of a twin crystal is given on p. 58 (Fig. 118). It is a niobate (or columbate) of iron with also some manganese, and further with the niobium there are also present varying amounts of the related element tantalum; as this increases the specific gravity runs up to about 7. Tantalite is nearly pure iron tantalate, with G. = 7.

Samarskite is a velvet-black mineral a little resembling columbite and often associated with it. Besides iron it contains tantalum, niobium, the cerium metals, yttrium, and other rare elements; it is found in the mica mines of North Carolina.

WOLFRAMITE, a tungstate of iron and manganese, is a still rarer mineral than columbite. It is iron-black in color, with fine cleavage and submetallic luster; like columbite it is very heavy, having a specific gravity of over 7.

TRIPHYLITE is a rather rare phosphate of lithium and iron chiefly ($LiFePO_4$), but containing also manganese and hence passing into LITHIOPHILITE ($LiMnPO_4$). It occurs in cleavable masses of a bluish-gray color; lithiophilite is salmon color, yellow or pale brown. Both minerals have similar physical characters: hardness 4.5–5; specific gravity 3.5; luster resinous. In the forceps they fuse readily, giving a red flame (lithium), with bluish green on the edge (phosphorus); they give with borax reactions for iron or manganese or both. CHILDRENITE is essentially a hydrated phosphate of iron and alumina, occurring in yellow or brown orthorhombic crystals. EOSPHORITE is the closely-related manganese compound.

VIVIANITE is a hydrated phosphate of iron having a blue to green color; it occurs in crystals, also in earthy forms, the latter called *blue iron earth*.

PHARMACOSIDERITE is a hydrated arsenate of iron commonly occurring in small cubic crystals of a yellow to green color. SCORODITE is another arsenate of iron which is found in olive-green to brown orthorhombic crystals, also in aggregations. There are numerous other arsenates and phosphates of iron, but too rare to be included here. Among the sulphates of iron may be mentioned MELANTERITE, also called iron vitriol and *copperas*, a mineral which has usually been derived from the decomposition of pyrite or marcasite. Copperas is employed in making ink, also much used by dyers and tanners.

NICKEL.

NICKEL, though formerly a little-used metal, has become of much wider application in recent years. It is extensively employed now to plate many articles of steel—as knives, scissors, skates, etc.—because unlike the steel it does not tarnish or rust rapidly in the air. It is much used also, when alloyed with copper, for small coins, as the "nickels" or five-cent pieces of this country, and similarly in Switzerland, Germany, and Belgium. Nickel steel has been found to be remarkably strong in withstanding the blow of a cannon-ball. The white alloy called "German silver" contains copper, zinc, and nickel in about the proportions of 5:3:2.

There are not, however, many minerals which contain nickel. One of these is the sulphide millerite; another is niccolite, or nickel arsenide. There are also some other rare compounds of nickel with sulphur, arsenic, or antimony. Nickel is also present in some varieties of the sulphide of iron, magnetic pyrites or pyrrhotite, and this occurs in so large an amount as to be an important source of the metal. There are further some hydrous silicates containing nickel, which are extensively mined at the present time. It is interesting to note, finally, though a matter of no practical importance, that the iron of meteorites is almost always an alloy of iron and nickel, the latter metal being present to the amount of 5 to 10 per cent, and in rare cases much more.

✱ **Millerite.** Nickel sulphide, NiS. ✱

MILLERITE, the sulphide of nickel, is remarkable among minerals because of its occurrence in very fine hairlike, or capillary, forms. These sometimes resemble a wad of hair, as in the geodes in the St. Louis limestone, or they may be simply a tuft of extremely delicate radiating crystals as in cavities of hematite at Antwerp, N. Y. There are also thin crusts with fibrous structure, as those from Pennsylvania. The hardness is a little over 3, and the specific gravity 5.6. It has a metallic luster and a color like that of yellow bronze, often slightly tarnished; the streak is greenish black.

The composition, NiS, gives 64.6 per cent of metallic nickel. Before the blowpipe millerite reacts for sulphur, like the sulphides, and after roasting off the sulphur a small fragment will give with borax in the oxidizing flame a characteristic violet bead (p. 138). The globule obtained on charcoal, after heating in the reducing flame, is attracted by a magnet, for nickel is a magnetic metal like iron, though of much feebler intensity.

It is only rarely that millerite occurs in sufficient quantity to be useful as an ore of nickel. An iron-nickel sulphide called PENTLANDITE is more important; POLYDYMITE is another nickel sulphide.

✱ **Niccolite.** Nickel arsenide, NiAs. ✱

NICCOLITE is often called copper-nickel, but not because it contains copper, but only from its conspicuous pale copper-red color. It is found in masses of metallic luster; hardness 5 to 5.5, and specific gravity 7.3 to 7.6. The composition NiAs gives: Arsenic 56.1, nickel 43.9 = 100.

BREITHAUPTITE is a related mineral, rarer than niccolite, though somewhat resembling it. It is an antimonide of nickel, NiSb.

Nickel is also present with cobalt in the mineral smaltite.

GENTHITE and GARNIERITE are hydrous silicates of nickel and magnesium of varying composition, having a bright green color. They are found only in massive forms and are not very interesting as minerals, but highly valuable as ores. Garnierite is mined extensively in the French penal colony of New Caledonia.

COBALT.

COBALT is a metal related to nickel and often associated in nature with it in its various compounds, though of much more limited occurrence.

Cobalt minerals are rather rare; they include the sulphide, LINNÆITE; the arsenide, SMALTITE, which is the chief ore; the sulph-arsenides, COBALTITE, and GLAUCODOT. All these have a tin-white color like that of arsenopyrite, which also has a variety, called danaite, which contains cobalt. There is also a bright rose-red mineral called ERYTHRITE, or cobalt bloom, which is an arsenate of cobalt. An impure oxide of cobalt is a black earthy mineral.

Cobalt, as a metal, is not used in the arts, but its salts, which are mostly brightly colored, have some applications. From the change in color that some of them undergo on heating and losing water depends their use as sympathetic ink. Cobalt glass, called *smalt,* has a beautiful blue ultramarine color and ground up is used as a pigment.

MANGANESE.

MANGANESE is a metal which is closely allied to iron in physical characters and chemical relations. As obtained by the chemist, for it does not occur in nature, it is hard and brittle; it has a grayish-white color, and a specific gravity of about 8. Like iron it forms numerous natural compounds, but they do not find many applications in the arts. The alloys of manganese with iron, called *spiegeleisen* and *ferromanganese,* are, however, employed in large quantities in making steel, and most of the manganese mined is used in this way.

The common ores of manganese are the oxides, pyrolusite and manganite; the silicate and carbonate are beautiful minerals, but relatively rare, as is still more true of the other natural compounds.

Pyrolusite. Manganese dioxide, MnO_2.

PYROLUSITE is an oxide of manganese, MnO_2, and because of the large amount of oxygen that it contains it is sometimes used in the laboratory as a source for that gas. The glass-maker also employs it to take out the color of glass, because the oxygen which it yields forms colorless compounds in it. On this account it takes its name, from the Greek words meaning fire (πῦρ) and to wash (λύω). The French have a similar name—they called it "glass-maker's soap." It is also used as an oxidizing agent in making paints, varnishes, etc.

It is a very soft mineral, soiling the fingers; it has a grayish-black color, a black streak, and metallic luster. It usually occurs in fibrous masses, less often crystallized, also sometimes in stalactitic forms and in incrustations.

The composition of pyrolusite is essentially manganese dioxide, MnO_2, but it also commonly contains some water. The strictly anhydrous manganese dioxide is the mineral *polianite*, crystallizing in tetragonal forms similar to crystals of rutile (TiO_2) and cassiterite (SnO_2). The reactions of manganese with the fluxes are given on p. 138. Heated in the closed tube pyrolusite yields oxygen which causes a match if still glowing when inserted to start into flame; when treated with hydrochloric acid chlorine is liberated. Pyrolusite is the common ore of manganese and is mined in large quantities in Virginia, Georgia, New Brunswick, etc. It has ordinarily, perhaps always, been formed from the related mineral manganite.

Manganite. Manganese hydrate, $Mn_2O_3.H_2O$.

MANGANITE is another oxide of manganese; it occurs in brilliant orthorhombic prismatic crystals and in fibrous radiated masses. The hardness is 4, and the specific gravity 4.2 to 4.4; the luster is metallic, and the color dark steel-gray to nearly iron-black, while the streak is dark reddish brown, thus distinguishing it from pyrolusite, the streak of which is black.

The formula $MnO(OH)$ or $Mn_2O_3.H_2O$ gives the percentage composition: Manganese sesquioxide 89.7 (or manganese 62.4), water 10.3 = 100. This is a not uncommon mineral in the Lake Superior iron region; it is mined in the Harz in Germany. By loss of water and oxidation it is converted into pyrolusite.

BRAUNITE and HAUSMANNITE are other oxides of manganese of rather rare occurrence. PSILOMELANE is commoner, but not often found in a state of purity; it usually occurs in black botryoidal or stalactitic forms, often associated with pyrolusite. It consists chiefly of manganese oxide and water, with some baryta, etc. WAD, or bog manganese, is a still less definite mineral, consisting of mixtures of oxides of manganese and other metals (cobalt, lead, etc.). It is brown to black in color, dull in luster; very soft, and often extremely porous and light, sometimes sufficiently so to float on water. It is used as a paint.

Rhodonite. Manganese silicate, $MnSiO_3$. *

RHODONITE is named from the Greek word for rose (ῥόδον), which alludes to its beautiful rose-red color. It is not a common mineral, but is found rather abundantly in some localities, as at Franklin Furnace, N. J., also in Russia, where it is used as an ornamental stone, in the form of a veneering for table-tops, etc. The crystals are flat and usually show two cleavages; they belong to the triclinic system, and the form is not easily deciphered.

The hardness is about 6, and the specific gravity 3.6. The luster is vitreous, or pearly on the cleavage faces; the color is rose-pink; the streak is white.

The formula, $MnSiO_3$, corresponds to the percentage composition: Silica (SiO_2) 45.9, manganese protoxide (MnO) 54.1 = 100. Some varieties contain zinc, others iron, and others also lime. It fuses rather easily before the blowpipe, turning black; with borax it gives a manganese reaction (p. 138). It is partially dissolved by hydrochloric acid.

Rhodochrosite. Manganese carbonate, $MnCO_3$.

RHODOCHROSITE, the carbonate of manganese, is another rose-colored mineral resembling rhodonite in color as in its name. It sometimes occurs in fine clear rhombohedrons, and in masses with rhombohedral cleavage, and then the form is found to be very near that of calcite and siderite, to which it is closely related (see p. 119); the angle between two cleavage faces is 107°. It also occurs in massive forms, sometimes granular and compact; also globular or botryoidal. The hardness is about 4, and the specific gravity 3.6. The luster is vitreous, and the color rose-pink; the streak is white.

The formula, $MnCO_3$, requires: Carbon dioxide (CO_2) 38.3, manganese protoxide (MnO) $61.7 = 100$. It effervesces with acid and reacts for manganese with the fluxes (p. 138). Beautiful clear rhombohedral crystals come from Lake County, Colorado. It is the gangue of silver and gold ores in Montana, near Butte City. It is mined in Wales and in Belgium.

Of the many other manganese minerals may be mentioned the sulphides ALABANDITE (MnS) and HAUERITE (MnS_2); further, the phosphate TRIPLITE (also triphylite and lithiophilite, p. 225); there are a number of other rare phosphates.

ZINC.

Zinc is one of the most common and important of the metallic elements, but it is not certainly known to occur in the form of the metal in nature. It has a crystalline structure like metallic antimony, a white color, and brilliant luster, soon, however, tarnishing. Its specific gravity is 6.9 to 7.2. It is brittle at both low and high temperatures, but at 140° Centigrade it can be rolled into sheets. It fuses at a relatively low temperature, 500° C., and boils at a red heat. Its physical properties put it somewhat near the imperfect metal antimony.

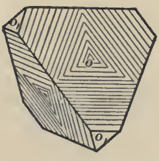
It is a most important metal in the arts. Iron in sheets and wire, coated by zinc, are protected from rusting, and are then said to be *galvanized;* a common use of the sheets is for roofing. Zinc is the negative metal in almost all forms of the chemical electric battery—that is, the metal at the expense of which the electric current is obtained. With copper it forms brass and related alloys; it is also one of the constituents in german silver; an alloy of zinc is used for making raised cuts in photo-engraving. The white oxide is used for paint. Metallic zinc, as obtained from the furnace in ingots, is called *spelter*.

The commonest ore of zinc is the sulphide, sphalerite or zinc blende, but the silicates, willemite and calamine, and the carbonate, smithsonite, are also important and valuable.

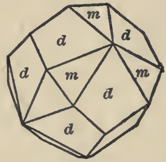
✱ **Sphalerite.** Zinc sulphide, ZnS.

Sphalerite is named from a Greek word which means *deceiving*, and the young mineralogist, after he has blundered over it a score of times, as he is pretty sure to do,—for it is far from easy to recognize,—will think it well named. It was so called because often occurring with and mistaken for the more easily recognized lead ore, galena; the miner's names, *black jack, false lead, false galena,* refer to the same fact. The common name, blende or zinc blende, will perhaps be easier to remember at first than sphalerite.

203.



204.



It is sometimes found in tetrahedral crystals and related forms (Figs. 203, 204), but usually the crystals are indistinct, being not infrequently twinned, and it needs a trained and skillful eye to understand them. Usually it is found in masses or small particles, showing smooth surfaces of cleavage, which is found on examination to be *dodecahedral,* since the angle between two adjacent surfaces is 120°. Sometimes it is possible to cleave out an almost perfect dodecahedron from a mass of sphalerite. Even if granular in structure the cleavage surfaces are usually prominent, though there are kinds which are closely compact and show no cleavage.

The hardness is 3.5 to 4, and the specific gravity about 4. When perfectly pure, sulphide of zinc is white in the form of powder, or clear and nearly colorless in small cleavage pieces; the latter then show an adamantine luster. Commonly it contains some iron, and often a good deal, and then the color is yellow or yellowish brown, —the latter the most common,—and finally dark brown and nearly or quite black; the light-colored kinds may also have a greenish tinge. The luster is usually resinous; and in all the common kinds this is so distinct that the mineralogist comes to depend upon it to enable him to identify the mineral. The streak is white, pale yellow, or brownish, becoming deeper the darker the color of the mass.

The composition zinc sulphide, ZnS, gives: Sulphur 33, zinc 67 = 100. As stated above, iron is usually present, and sometimes also manganese and the rare element cadmium. Before the blowpipe it does not fuse, but if powdered and heated on charcoal (see p. 143) it gives a zinc coating, canary-yellow when hot, but white on cooling; this turns green when heated in the oxidizing flame after being moistened with nitrate of cobalt. When warmed in a test-tube with hydrochloric acid it effervesces, giving off bubbles of gas which a careless observer might take for carbon dioxide, only the disagreeable odor shows that it is sulphureted hydrogen (H_2S).

Zinc blende is one of the commonest of the metallic compounds, and where we find galena or pyrite we are likely to find it also; in one variety it is compact, alternating in layers with cleavable galena. It occurs in some regions, as in southwestern Missouri and the adjoining portions of Kansas, in very large deposits.

Zincite, Franklinite, and Willemite are all rare minerals, but as they are important ores of zinc at that famous locality, Franklin Furnace, New Jersey, they will be mentioned briefly; they are indeed known at only a few other places.

Zincite, or the red oxide of zinc (ZnO), is often found in bright red grains or masses, sometimes mixed up with the other two minerals named, the black franklinite and the green willemite. It also occurs in larger masses in calcite, and then shows good cleavage. Hexagonal crystals are very rare. The hardness is 4 to 4.5, and the specific gravity 5.4 to 5.7. The deep red or orange color is very characteristic; the streak is orange-yellow. It reacts for zinc on charcoal and for manganese with borax on the platinum wire.

Franklinite is an oxide of zinc, manganese, and iron; it has been already mentioned on p. 221.

Gahnite, or zinc spinel, is related to franklinite. It has often an octahedral form and a deep green color. The hardness is 7.5 to 8, and the specific gravity 4.6. The typical composition is $ZnO.Al_2O_3$, but kinds from different localities vary widely.

Willemite is often found in bright yellow or apple-green masses, also in six-sided crystals usually of a flesh-red color and which are sometimes quite large and have a resinous luster; this last kind is called *troostite*. Rarely slender prisms of a clear green are found. The hardness is 5.5, and the specific gravity 3.9 to 4.18. The luster is between vitreous and resinous, often weak, and the color varies widely, as already stated.

Willemite is a silicate of zinc, Zn_2SiO_4, or $2ZnO.SiO_2$, and the percentage composition is: Silica (SiO_2) 27.0, zinc protoxide (ZnO) 73.0 = 100. Manganese and iron are often present, replacing part of the zinc.

Calamine is another silicate of zinc, but different from willemite, since it contains considerable water, which it gives off when heated to a high temperature in the closed tube. It is not very often found in isolated crystals, but usually in masses with a crystalline surface, which is mammillary or botryoidal in form. Occasionally the surface is seen to be made up of flat tabular crystals projecting from the mass. The hardness is 4.5 to 5, and the specific gravity 3.4 to 3.5. It is usually white or slightly yellowish, but may be tinged blue from a little copper; the luster is vitreous.

The composition is $H_2Zn_2SiO_5$ or $H_2O.2ZnO.SiO_2$, which gives: Silica (SiO_2) 25.0, zinc protoxide (ZnO) 67.5, water (H_2O) 7.5 = 100. Before the blowpipe on charcoal it yields the characteristic zinc coating; further, a fragment ignited with cobalt solution assumes a fine blue. With hydrochloric acid it forms a jelly (p. 156).

Smithsonite. Zinc carbonate, $ZnCO_3$

Smithsonite is remarkable because in its common forms looking so much like calamine. Like it it may have many colors—indeed, the smithsonite brought of recent years from the old zinc mines of Laurium in Greece is remarkable for the beautiful shades of blue, green, yellow, and red which it exhibits in different specimens. It is also called *dry bone* by the miners. It is related to calcite, siderite, and rhodochrosite, and crystallizes in similar rhombohedral crystals (p. 119), but they are very rare. The common form is that of mammillary or botryoidal masses, also stalactitic shapes. The hardness is 5, and the specific gravity 4.3 to 4.45. The luster is vitreous.

The composition $ZnCO_3$ gives: Carbon dioxide (CO_2) 35.2, zinc protoxide (ZnO) 64.8 = 100. With acid it effervesces, as do all the carbonates. It is infusible before the blowpipe, but when heated very hot in the oxidizing flame after moistening with cobalt solution it takes a green color on cooling.

CADMIUM is a rare element often associated with zinc, for instance in sphalerite. GREENOCKITE is cadmium sulphide.

ALUMINIUM or ALUMINUM.

ALUMINIUM is one of the most remarkable of metals, because while it has great tenacity and is in a high degree sonorous and non-oxidizable in the air, it has a specific gravity of less than calcite, or only 2.5. In other words, it is only about one third as dense as iron and one fourth as dense as silver, which it somewhat resembles. Both as the pure metal, because of its low density, and in alloys, for example with copper as aluminium bronze, because of their strength and other remarkable properties, it is highly useful. As improved methods of obtaining it are devised (e.g., by electrolysis) and the price, once very high, falls, its use is being increased, and we cannot now say to what extent in the future it may supplant other metals, especially steel.

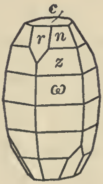
Aluminium does not occur in the native form, but it is one of the commonest of the chemical elements and is an important constituent of a great many minerals.

Corundum is oxide of aluminium; gibbsite and bauxite are hydrated oxides, the latter occurring in large quantities, but more or less impure; cryolite is a fluoride of aluminium and sodium; kaolin is a silicate of aluminium, and the many kinds of clay are related silicates, though usually impure; the feldspars are silicates of aluminium with potassium, calcium, or sodium; further, the element enters into the composition of a considerable part of the other silicates, as mica, the zeolites, etc. The supply of the metal is now chiefly obtained from bauxite, also from gibbsite and cryolite.

* **Corundum.** Alumina or Aluminium oxide, Al_2O_3. *

CORUNDUM is, next to diamond, the hardest of minerals and one of great interest. Its clear blue varieties make the *sapphire* of jewelry, and the clear red the highly-prized *ruby;* while the coarse and impure kinds, when pulverized, are our *emery.* When in distinct crystals it has a hexagonal form, usually either that of a prism or a tapering pyramid (Figs. 205, 206). It is also found in massive forms, and these often have a fracture nearly like a cube in angle.

205.



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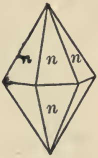

The hardness is 9, so that it will scratch any other mineral except the diamond. The specific gravity is 4.0, which is high for a nonmetallic mineral, and remarkably high for the oxide of a metal of such low density. It is not often that the oxide of a metal is more dense than the metal itself; this great density is obviously connected with the great hardness (see p. 84). The luster, like that of most very hard minerals, is brilliant and adamantine, though rather dull in some massive kinds. The color is gray to brown or nearly black in many of the common varieties, called in part *adamantine spar;* bright blue in the variety called the *sapphire;* red in the *ruby;* purple in the *Oriental amethyst;** yellow in the *Oriental topaz.*

Corundum is the sesquioxide of aluminium, Al_2O_3. It is infusible before the blowpipe and unattacked by acids. When heated very hot it gives with cobalt nitrate the characteristic blue of alumina. To obtain this, since the mineral is so refractory, it should be pulverized carefully, then moistened with a drop of nitrate of cobalt, so as to form a paste, and this supported in the loop of the platinum wire and intensely heated.

Common corundum occurs in Massachusetts at Chester, New Jersey, Pennsylvania, and still more in North Carolina and the adjacent states of South Carolina and Georgia; gems are rare, but when pulverized and washed from the rock it is used for emery. Beautiful sapphires have been obtained in Ceylon, and rubies in Siam and Burma and other places in the East Indies. Emery has been extensively mined near Smyrna, Asia Minor, and at Naxos and other of the Greek islands.

DIASPORE is a rare oxide of aluminium ($Al_2O_3.H_2O$) yielding about 15 per cent of water upon ignition. It occurs in thin crystals or foliated masses with highly perfect cleavage; the luster on the cleavage-face is pearly, elsewhere vitreous. The color is usually white or nearly so. The hardness is 6.5 to 7, and the specific gravity 3.4. This species is often associated with corundum, as at Chester, Mass., in Pennsylvania at Newlin, and elsewhere.

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* The word Oriental in such cases was formerly much used; it meant originally coming from the East or Orient, and from that, as applied to gems, of great value as contrasted with stones of similar color (for example, the common amethyst) but not so highly prized.

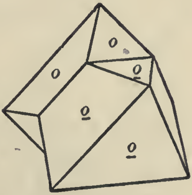
BAUXITE is a hydrated oxide of aluminium occurring in earthy masses resembling clay; also in concretionary forms. The color varies from white to gray, yellow, also to brown or red, especially in the impurer kinds. It is not an attractive mineral, but is valuable as a source of aluminium. It takes its name from the principal locality at Baux (or Beaux), France; it is also found in our Southern States.

GIBBSITE is a hydrated oxide of aluminium, $Al(OH)_3$ or $Al_2O_3.3H_2O$. It occurs in opaque white stalactitic forms and incrustations, showing a radiated structure. It is often found with ores of iron and manganese, but not usually in large quantities.

Spinel. Magnesium aluminate, $MgAl_2O_4$.

SPINEL is a rather rare mineral containing in the typical form magnesia and alumina. It is usually found in octahedrons, often in twins, which are therefore called spinel twins (Fig. 207). The hardness is 8, or as great as that of topaz, and the specific gravity 3.5 to 4. The color is sometimes pink, as in the spinel ruby or *balas ruby*, which is not to be confounded with the true or Oriental ruby. It is also blue and black. The typical composition

207.



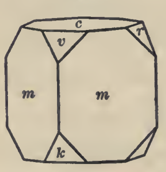
is $MgAl_2O_4$ or $MgO.Al_2O_3$, but different kinds vary widely from this.

CHRYSOBERYL is another rare mineral containing beryllium and alumina ($BeO.Al_2O_3$). It is interesting because very hard (H. = 8.5), and in some of its forms used as a gem, especially a grayish-green kind (from Ceylon) with chatoyant effect, hence called *cat's-eye;** also in a variety from Siberia named *alexandrite,* which is green as ordinarily seen, but red by transmitted light (see Fig. 121, p. 58). The common form has a greenish-yellow color, a little resembling beryl, whence it takes its name of golden beryl.

Cryolite. Fluoride of Aluminium and Sodium, Na_3AlF_6.

CRYOLITE takes its name from two Greek words (κρύος, λίϑος) which mean *ice-stone,* and it is so called because often found in blocks which have something of the appearance, as slightly clouded, of blocks of ice; it is remarkable for its easy fusibility.

208.



It is found in crystals having nearly the angles of a cube, though really monoclinic (see Fig. 208); it also has cleavages in three directions, which, unless carefully examined, could be confounded with cubic cleavage. The hardness is 2.5, and the specific gravity 3. The luster is vitreous to greasy, and the color usually white, but sometimes reddish or brownish.

The composition, Na_3AlF_6, which may also be written $3NaF.AlF_3$, gives: Fluorine, 54.4, aluminium 12.8, sodium

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* The same name belongs to a less beautiful variety of quartz giving a similar effect.

32.8 = 100. It fuses with great ease even in small fragments in the candle-flame without the blowpipe. It gives an intense yellow flame (soda), and also reacts for fluorine.

Cryolite is a rare mineral, and the only locality where it occurs in quantity is near Ivigtut in Southern Greenland. Here it has been mined for many years, because useful both for making soda salts and as an ore of aluminium (it is brought to Philadelphia for this purpose). It is also found sparingly in Colorado.

THOMSENOLITE and PACHNOLITE are fluorides of aluminium, calcium, and sodium, which are related to cryolite and occur with it.

TURQUOIS, the beautiful precious stone having the color of robin's-egg blue, also bluish green in less highly prized varieties, is a hydrated phosphate of aluminium, containing also a little copper phosphate, which is probably the source of the color. It occurs only in compact massive forms, filling seams and cavities in a volcanic rock. The early locality was in Persia, but of late years a number of mines have been opened in New Mexico—some of them were worked hundreds of years ago by the Mexicans.

WAVELLITE is another hydrated phosphate of aluminium. It is usually found in globular or hemispherical forms with radiating structure (see Fig. 133, p. 68) and a crystalline surface. The hardness is 3 to 4, and the specific gravity 2.3. The color is white, varying to yellow or green. There are a number of other related aluminium phosphates, but they are too rare to be included here, except perhaps the azure-blue LAZULITE found in monoclinic crystals in Georgia, also elsewhere in massive forms.

Amblygonite is a rare phosphate of aluminium and lithium containing fluorine ($AlPO_4.LiF$). It usually occurs in white cleavable masses resembling albite, but easily distinguished by its fusibility. It melts before the blowpipe very readily (at 2), giving a red flame (lithium) with traces of green (phosphorus). The hardness is 6, and the specific gravity 3.05. It is found in Maine.

Alunite is a sulphate of aluminium occurring in rhombohedral crystals looking a little like cubes. Another sulphate is **Aluminite**. The **Alums** are hydrous sulphates of aluminium with potash, soda, etc. There are numerous such compounds among minerals.

Dawsonite, from near Montreal, is a rare carbonate of aluminium and sodium.

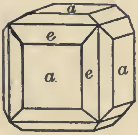
CALCIUM.

Calcium, whose oxide (CaO) is the familiar substance called *lime*, is a white metal somewhat resembling silver or tin. It is obtained with difficulty, for example by electrolysis (p. 107), and is in this form of interest only to the chemist. Its compounds, however, are numerous and important, and it is indeed one of the most widely distributed of all the elements. The carbonate of calcium forms the common mineral calcite and also the less common aragonite. Other very important compounds among minerals are: the fluoride, fluorite or fluor spar; the phosphate, apatite; and the sulphates, gypsum and anhydrite. Calcium is also an essential ingredient of many of the silicates, as in some of the feldspars and zeolites, some varieties of pyroxene and garnet, and so on.

✱**Fluorite** or Fluor Spar. Calcium fluoride, CaF_2.

Fluorite, or Fluor Spar, is one of the most beautiful of minerals, occurring in cubic crystals and groups of crystals (see Fig. 2, p. 15), sometimes very large and of a great variety of colors, from colorless to green, yellow, brown, red, and purple. It is common to find the angles of one cube projecting from the faces of another, and as the position of the crystals is then such that if one of them were revolved 180° about a line joining opposite angles they would be brought into a parallel position, the group is called a twin (Fig. 211, also Fig. 116, p. 57). The edges of the cubes are often beveled by a pair of narrow planes (Fig. 209), and one, three, or six little faces (Fig. 210) are sometimes seen on the solid angles.

209.



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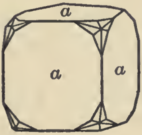

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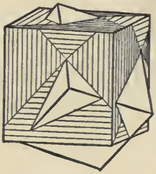


Octahedral crystals are also found—occasionally built up of minute cubes—and also other forms, but the cubic habit is so important a character that a non-metallic mineral of this form at once suggests fluorite to the careful mineralogist. These crystals, and the massive forms too, can often be recognized by the perfect octahedral cleavage which makes it easy to break off the angles of the cubes, and from a large cube to form by fracture a perfect octahedron.

Besides the crystallized forms there are others, not so easy to recognize, which are massive. These are often fibrous or columnar in structure, and one variety having the colors arranged in bands is used as an ornamental stone; this includes the Derbyshire *blue-john.* There are, too, granular kinds and those which are closely compact.

The hardness of fluorite is 4, and its specific gravity 3.2. The variety in color, embracing many shades of green and purple, yellow and red, has already been mentioned; there are also colorless kinds. The crystals are usually transparent, and sometimes show on, or near, the surface a bright bluish color quite different from that observed when they are looked directly through. The blue light extends within the crystal if it is placed in the direct sunlight. This phenomenon is called *fluorescence,* and having been first observed with fluorite was named accordingly from it. The name fluor spar is one of the oldest in mineralogy, and was given because of the use of this species as a flux in smelting.

Fluorite is one of a rather small group of compounds called fluorides; its formula is calcium fluoride, CaF_2, which gives the percentage composition: Fluorine 48.9, calcium 51.1 = 100. Powdered and warmed with sulphuric acid in a lead or platinum crucible it gives off hydrofluoric acid, and a plate of glass, first covered with a layer of wax and then written on by a fine point, will have the lines thus exposed etched by the acid. This method of ornamenting glass or of making marks, for example on a thermometer-stem, is often used.

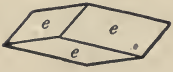
Fluorite usually flies to pieces violently when heated before the blowpipe; but when pulverized, as explained on page 131, it can be fused and yields the yellowish-red flame characteristic of lime. Broken into small fragments and heated in a closed tube, not too hot, it phosphoresces, that is, becomes self-luminous, emitting sometimes a yellow light, also, as in the variety chlorophane, a beautiful green. This is best seen in the dark. Even the blow of a hammer is enough to make a mass yield a faint but beautiful phosphorescent light for hours after.

Fluorite is a common mineral in lead veins, and is then said to form the "gangue" of the ore. It occurs in this way in Derbyshire and Cumberland in England, and in the Freiberg mining region of Saxony. It is also found in cavities in limestone, as at St. Louis. A cave lined with beautiful sea-green cubes, some of them very large, was opened at Macomb, N. Y., a few years ago. Besides the use of some colored varieties for vases, etc., the massive kinds are employed as a flux in smelting ores as already stated, also in making opalescent glass.

Calcite. Calcium Carbonate or Carbonate of Lime, $CaCO_3$.

CALCITE, next to quartz, is the most common of mineral species, remarkable for its variety of form both among the crystallized and uncrystallized varieties. It crystallizes in rhombohedrons and scalenohedrons of great variety and complexity of form, also in hexagonal prisms. The fundamental rhombohedron, Fig. 213, has an angle between two adjacent faces of 105° (terminal edge), and each face has plane angles of 102° and 78°. Parallel to the faces of this rhombohedron there is very perfect cleavage, so that a large mass breaks easily under the blow of a hammer into fragments all showing the same form (see Fig. 144, p. 72). This cleavage is the most important character of the crystallized varieties.

212.



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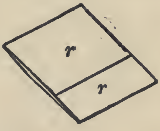

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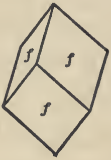

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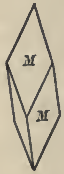

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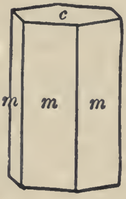

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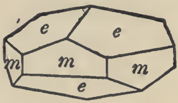

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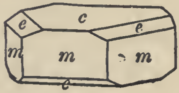

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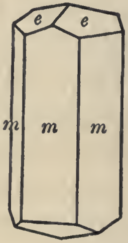

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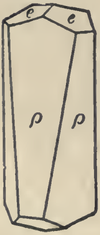

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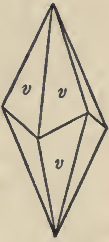

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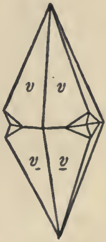

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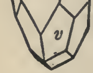


There are also other rhombohedrons, flattened or obtuse and lengthened or acute in the vertical direction, as shown in Figs. 212, 214, 215, 220. The rhombohedral angle for

e (Fig. 212) is 135°, for f (Fig. 214) 79°, for M (Fig. 215) is 66°. Fig. 216 represents a hexagonal prism, and Figs. 217, 218, 219 the same with the obtuse rhombohedron e of Fig. 212; the angle me is 116$\frac{1}{4}$° over the horizontal edge, and ce (Fig. 218) is 153$\frac{3}{4}$°. Fig. 221 shows the common scalenohedron, the angles for whose two kinds of terminal edges are 104° 40′ and 144° 24′; the angle for the zigzag edge is 133°. Fig. 222 is a similar scalenohedron twinned, and Fig. 223 a combination of prism (m), rhombohedron (r), and scalenohedron (v). See also Figs. 81, 82, p. 41. The variety crystallizing in scalenohedral forms, or in acute rhombohedrons, is often called *dog-tooth spar*. There are also crystals with a combination of faces, or highly modified crystals as they are called, which can only be deciphered by one who has a thorough knowledge of crystallography. The remarkable experiment by which a twinning structure may be imparted to a cleavage fragment is mentioned on p. 59; as there stated, twinning lamellæ, often of secondary origin, are very common in large rhombohedral crystals.

A clear cleavage mass of calcite, such as that brought from Iceland, is called *Iceland spar* and is useful for optical prisms. This is because of its remarkable double refraction, or power of dividing a ray of light passing through it into two separate rays, so that a line seen through it appears double. This phenomenon has been already described and illustrated (Fig. 148, p. 94).

Besides the crystallized kinds there are those which have a granular structure, as statuary marble, and which sparkle in the light because of the multitude of cleavage-faces. Other kinds are fibrous with a silky luster, like *satin spar;* also close and compact, as in ordinary *marble,* and then of great variety of color, red, yellow, blue, black, and largely used for ornamental purposes. Some of these kinds of marble still contain shells, which come out distinctly when polished. These shells are what we have to expect in such cases, for most limestone has been formed from the material of shells, crinoids, etc., left by animals whose remains have accumulated in large beds in the ocean and afterward been hardened, crystallized, and elevated into the position in which they are now found. A kind of shell marble with beautiful firelike reflections is called *lumachelle.*

224.

Stalactites and *stalagmites* are varieties of calcite which are formed in caverns in limestone rocks. The water, charged more or less with the gas carbon dioxide, has the power of dissolving these rocks as it works its way through them and the calcium carbonate in solution is again slowly deposited in the forms here described. The stalactites hang like icicles (Fig. 224) from the roof of the cavern, and the stalagmites are made by the deposit from the drippings on the floor beneath. They are sometimes very large and have often great beauty and variety of shape; a cave like the Luray cavern or the Adelberg grotto at Trieste is a fairyland of strange and beautiful forms. These deposits often have a banded structure and sometimes occur on a large scale, so that the rock can be quarried and used as an ornamental stone. The *Mexican onyx* is such a variety of calcite, a kind of stalagmite or water deposit, of great delicacy of coloring, beautifully translucent and used for ornamental purposes in a great variety of forms. Other kinds of calcite, formed by the deposit from waters containing carbonate of lime, are *calc sinter* or calc tufa, which often shows the impression of leaves; *agaric mineral* or rock-milk, a soft powdery material; *rock-meal,* a light white cottonlike substance.

Calcite in its normal crystallized varieties has a hardness of 3, and a specific gravity of 2.7. The luster is usually vitreous, but silky in satin spar and dull in some earthy forms. It may be quite colorless, or pale yellow, pink, blue, less often dark-colored except in the marbles, which are even jet-black.

Calcite is calcium carbonate, or carbonate of lime, $CaCO_3$, and the percentage composition is: Carbon dioxide (CO_2) 44, lime (CaO) 56 = 100. In the case of this mineral heat alone is enough to separate it into these two parts and this method is taken (as in a lime-kiln) both for obtaining the quicklime employed in making mortar, and also carbon dioxide, or carbonic-acid gas, used under pressure for charging soda-water fountains. Calcite does not fuse before the blowpipe, but a fragment after being heated (notice that it glows when ignited) and cooling turns a piece of moistened turmeric-paper brown (p. 131). In dilute hydrochloric acid it effervesces at once, giving off bubbles of carbon dioxide (carbonic-acid gas), and this is the simplest chemical test by which to identify it.

Dolomite (p. 260) and siderite (p. 223), which belong to the "Calcite Group" (see p. 119), effervesce in acid also, but only when in the state of a fine powder or on being heated.

The occurrence of some of the kinds of calcite has already been spoken of. Limestone rocks are found in great quantities at many points in the world; in the United States they are especially common through the central states of Illinois, Iowa, Wisconsin, etc. In cavities in these rocks the crystallized forms occur, beautiful cavities or geodes being very common. It is also found with ores of the metals, as of lead, copper, and silver, and often in beautiful crystals wonderful for their size and complexity of crystallization. The mines of Lake Superior afford fine specimens, also those of Derbyshire and elsewhere in England and the Harz region of Germany.

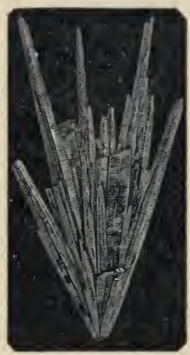
Calcite in its crystalline varieties is easily recognized by its cleavage and softness, and a drop of acid on a fragment in a watch-glass or test-tube effervesces at once.

Calcite is useful, as already stated, for optical purposes in the form of Iceland spar; also as an ornamental stone and for building purposes in the many kinds of marble. Common limestone when burned yields the quicklime essential for mortar; further, the lime obtained from certain kinds, containing some foreign substances (as silica and alumina) has the property of becoming firm and solid under water and is hence called *hydraulic lime*, the limestone being then named *hydraulic limestone.*

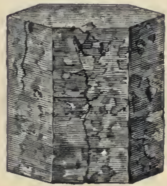
✱ **Aragonite.** Calcium carbonate, $CaCO_3$.

ARAGONITE is also calcium carbonate, having thus the same composition as the species calcite; but it crystallizes in the orthorhombic system, and though the forms may occasionally look like those of calcite, they are easily distinguished because they do not show its cleavage. The crystals are commonly slender needles (Fig. 225); there are also six-sided prisms which are really compound or twin crystals (Fig. 226). Besides these there also occur other kinds, as the delicate coral-like *flos-ferri*—or flower of iron—found in iron mines (Fig. 227), and further massive kinds.

225.

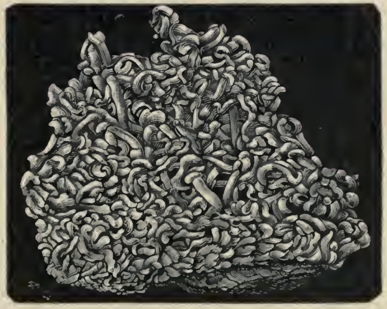


226.



Aragonite is a little harder than calcite, 3.5 to 4 instead of 3, and distinctly denser, 2.9 instead of 2.7. Its luster is vitreous mostly, but on the cross-fracture of crystals plainly resinous, which aids the skilled eye in recognizing

227.



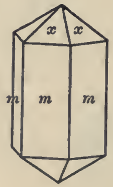
this species. The composition of aragonite and its behavior with acid and before the blowpipe are the same as with calcite.

Aragonite is not so common as calcite, but like it is a deposit from waters containing calcium carbonate; the question of temperature is an important element in determining which of the two species is formed.

✱ **Apatite.** Calcium phosphate, $3Ca_3P_2O_8.CaF_2$.

APATITE can usually be recognized by its hexagonal form. A common kind is that occurring in long six-sided prisms, terminated by a low hexagonal pyramid (Figs. 228, 229); another is in short, stout hexagonal prisms, with often a large number of modifying planes (Fig. 230); and still another is like a low pyramid. The angle between two adjacent pyramidal faces (x) is 142° 16′, and that of x on m is 130° 18′, of x on c 139° 42′. There are also massive forms showing no crystallization.

228.



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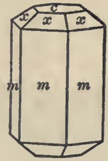
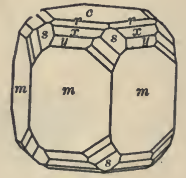


230.



The hardness is 5, so that it can be scratched, but not very easily, by the knife; its specific gravity is 3.2. The luster is usually vitreous, but sometimes resinous. The common color of the long prisms is a dull green, but they are also yellow, red, brown, black, and sometimes violet;

the smaller crystals are often clear and colorless; a variety in clear yellow-green crystals is called asparagus-stone.

Apatite is essentially calcium phosphate, $Ca_3(PO_4)_2$, but it also contains a little fluorine or, less often, chlorine (or both), and the two varieties are distinguished as *fluor-apatite* and *chlor-apatite.* This distinction is not a very important one and can be made out only by a chemical analysis. Apatite is difficult to fuse before the blowpipe, and on this account it does not give the bluish-green color characteristic of phosphoric acid, unless first touched with a drop of sulphuric acid. It is easily soluble in hydrochloric acid, also in nitric acid: and if to this last some ammonium-molybdate solution (in nitric acid) is added, a bright yellow powdery precipitate separates on gently heating; this is a delicate test for phosphoric acid.

Apatite is a rather widely disseminated mineral, as in granite, also in limestone, and with ores of iron and tin; in many igneous rocks it occurs, as revealed by the microscope, in minute crystals. It is also found in large crystals, sometimes as big as a nail-keg, and in masses, associciated with pyroxene, scapolite, titanite, also zircon, vesuvianite and other species, in veins in the crystalline rocks of Canada and Norway; in both countries it has been mined extensively in recent years. By treating with sulphuric acid soluble phosphate is formed, which is employed to fertilize the land. Phosphorus is also manufactured from apatite.

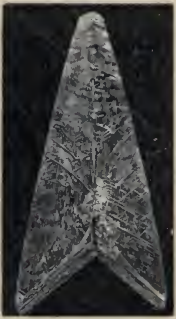
Related to apatite is the phosphate rock, which forms extensive phosphate deposits in South Carolina and Florida; this has a great economic importance. Guano, as of the West Indian islands, also consists largely of calcium phosphate.

Gypsum. Calcium Sulphate or Sulphate of Lime,
$CaSO_4 + 2H_2O$.

GYPSUM occurs in monoclinic crystals, and these often have the form shown in Fig. 231; twin crystals are ~~also~~ also common, especially those of the "swallow-tail" type, like Fig. 232.

231.

232.

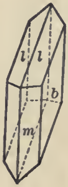


The crystals have very perfect cleavage parallel to the side face (*b*) of Figs. 231 and 233, and sometimes very large thin and perfectly transparent plates may be obtained.

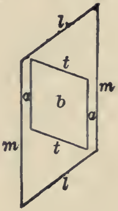
The variety yielding these is called *selenite* (from the Greek word, σελήνη, meaning *moon*). These plates look a little like mica, but are much softer, and, though somewhat flexible, are yet brittle and quite inelastic. When broken carefully a plate parallel to *b* (Fig. 234) shows also two other cleavages: in the direction of the front edge (*m* or *a*) it breaks rather sharply with a conchoidal edge, while in the direction of *t* in the figure the plate is somewhat flexible and separates with a fibrous fracture. The plane angles of this cleavage plate, *at*, shown in Fig 234, are 66° and 114°. Further, the angle of the front edge *mm* of Fig. 233 is 111½°, and of the edge *ll* is 143¾°.

Gypsum also occurs in fibrous forms called, like the similar variety of calcite, *satin spar;* it is easily distinguished from calcite because so much softer. There are, further, foliated and stellate forms (see Fig. 134, p. 68) and those which are granular and, again, earthy, as in impure massive gypsum.

233.



234.



The hardness of gypsum is only 2, and it is hence easily scratched by the nail, though not, on the other hand, having the very soapy feel of talc (whose hardness is 1); the specific gravity is 2.3. The luster is pearly on the face of perfect cleavage, otherwise subvitreous; it is also silky in some fibrous forms, and in earthy kinds dull. The selenite variety is clear and colorless; the massive kinds are generally snowy white, as in the variety called *alabaster,* though they may be reddish and, when quite impure, almost black.

Gypsum is hydrous calcium sulphate, $CaSO_4 + 2H_2O$, which gives the percentage composition: Sulphur trioxide (SO_3) 46.6, lime (CaO) 32.5, water (H_2O) $20.9 = 100$. It dissolves quietly in hydrochloric acid. In the forceps a fragment becomes opaque white and exfoliates, fusing to a globule which gives an alkaline reaction with turmeric-paper. A large amount of water is given off freely in the closed tube, and the residue is finally the anhydrous sulphate. This is made on a large scale and called plaster of Paris, because so produced near Paris. This substance has the property of becoming very hard when ground and mixed with water, and is hence extensively used for making plaster casts, for the *hard finish* for walls, and for other uses. Gypsum is also largely used when ground up for improving soils. The variety alabaster is soft and easily cut into vases and other ornamental objects.

Gypsum is a very common mineral, forming extensive beds in regions of limestone, also present in clay beds and in connection with deposits of rock-salt and salt-wells. It is found in curious forms in the Mammoth Cave, Kentucky.

ANHYDRITE receives its name because, while consisting of calcium sulphate ($CaSO_4$), it does not, like gypsum, contain water. It is rarely found in crystals, more commonly in forms with what looks like cubic cleavage, but careful examination shows that the three cleavages are unlike, and optical examination confirms this and proves the species to belong to the orthorhombic system. There are also compact kinds. The hardness is 3 to 3.5; specific gravity about 3; the luster vitreous to pearly; color white to gray or bluish, also red. It is not a common mineral, and is usually associated with rock-salt and gypsum.

SCHEELITE is a mineral consisting of calcium tungstate ($CaWO_4$). Like other tungsten compounds it has a high specific gravity ($G. = 6$), in fact there is perhaps no other mineral, outside of the compounds of lead, which like this is white to pale yellow in color, or even colorless, and at the same time has so high a density. It is found in tetragonal crystals or massive forms, and is often associated with cassiterite (tin-stone), topaz, fluorite, and other species.

It is interesting to note here that some compounds of tungsten are used for pigments; sodium tungstate has the effect of making cloths soaked in it entirely incombustible. Tungsten is also employed in certain rare alloys.

Of the many other natural compounds of calcium, the following may be mentioned.

PHARMACOLITE is a hydrous arsenate occurring in white monoclinic crystals, more commonly in silky fibers or botryoidal forms. The color is usually white or grayish.

COLEMANITE is calcium borate, occurring in fine monoclinic crystals, colorless or milky white, in San Bernardino County, California. ULEXITE is a borate containing both calcium and sodium.

PEROVSKITE is calcium titanate, a rare mineral occurring in isometric crystals. MICROLITE is essentially calcium tantalate; it is mentioned again on a later page (p. 271).

MAGNESIUM.

MAGNESIUM is the metal which is present in the oxide (MgO) called magnesia. It is a white metal resembling calcium and closely related to it chemically. In the form of a thin strip or ribbon it burns readily in the air, yielding a very brilliant white light, which is often used as a source of illumination in photography. The chemical product of the combustion is the white oxide just spoken of. There are a number of prominent compounds of magnesium occurring among minerals, and it enters into the composition of many of the silicates.

Brucite. Magnesium hydrate, $Mg(OH)_2$.

BRUCITE is found in white or greenish scales or plates, with perfect cleavage, often transparent. These are hexagonal in outline, but they may be united together in rosettelike groups, and then the form is not distinct. There is also a fibrous variety called *nemalite.*

The hardness is only 2.5, so that the plates are about as hard as mica, which they somewhat resemble; on the other hand, they are a little harder than gypsum, and much more so than talc. The luster is distinctly pearly, and the color often slightly greenish.

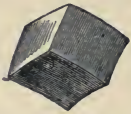
Brucite is the hydrate or hydrated oxide of magnesium, $Mg(OH)_2$ or $MgO.H_2O$. In the closed tube it yields water, and a fragment heated in the forceps turns opaque from loss of water, and after being moistened with cobalt solution and again ignited it assumes a pale pink color—the reaction for magnesia.

MAGNESITE, the carbonate of magnesium, $MgCO_3$, is not a common mineral. It is found, but only rarely, in crystals and cleavable forms, which are interesting because resembling some of those of calcite, but the ordinary form is that of a white compact mass looking like chalk, but harder.

* **Dolomite.** Calcium-magnesium carbonate, $CaMg(CO_3)_2$.

DOLOMITE, the carbonate intermediate between calcite and magnesite, is a common and important mineral. It has the same form as calcite, and often cannot certainly be distinguished from it by simple inspection. The crystals have one peculiarity, however, in that the rhombohedral faces are almost always curved, giving a convex surface. This is not true of calcite, but is the case with rhombohedrons of siderite, the carbonate of iron; so that the figure (Fig. 235) given of that species is repeated here. Sometimes the crystals are formed of many smaller crystals, and all so much curved as to give a saddle-shaped form, as illustrated in Fig. 236. The white cleavage-masses of dolomite also sometimes show slightly curved surfaces, but this is not universally true, and the granular forms look like granular calcite.

235.



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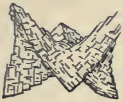


Dolomite is a little harder than calcite, H. = 3.5 to 4, instead of 3, and a little denser, G. = 2.8 to 2.9. It also differs in being less easily attacked by acid; thus a fragment of calcite dropped into cold dilute hydrochloric acid effervesces strongly at once, while a similar piece of pure dolomite is hardly attacked at all, and the effervescence does not start up unless the acid is warmed or the mineral pulverized. The luster is vitreous, though pearly in some kinds; it varies from colorless to white and pale green, pink, and brown; it is transparent to translucent.

Normal dolomite, as it is called, or the common crystallized dolomite, consists chemically of the carbonates of calcium and magnesium in equal proportions, $CaMgC_2O_6$ or $CaCO_3.MgCO_3$. In other kinds, however, the ratio of the two carbonates may vary somewhat widely. There are also other related minerals (as ANKERITE) which contain iron as well as calcium and magnesium, and others which contain magnesium and iron only (as BREUNERITE and MESITITE). Much white marble is dolomite, not calcite.

BORACITE is a rare borate of magnesium containing chlorine. It occurs in glassy crystals which are tetrahedral like Figs. 31 to 35, p. 29; color also white to yellow or gray. Hardness = 7; specific gravity 2.9 to 3; luster vitreous, inclining to adamantine. In the forceps it fuses easily, yielding a green flame (boron) and turning pink with cobalt solution (magnesium, see p. 260).

EPSOMITE is hydrated magnesium sulphate, occurring sparingly as a mineral, for example in some caves. The artificial compound is commonly employed in medicine.

Magnesium is also present in a great many silicates, as talc, serpentine, sepiolite or meerschaum, also the varieties of pyroxene and amphibole; further staurolite, some tourmaline, etc.

BARIUM.

BARIUM is a metal only known in the laboratory, where it can be obtained from some of its compounds. It is a heavy metal, and takes its name from this fact from the Greek word for heavy (*βαρύς*). All of its salts have also high density.

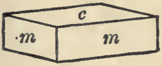
The chemist can make a large variety of compounds of barium, but the only prominent minerals in which it occurs are the sulphate, barite, and the carbonates, witherite and barytocalcite. It also appears in a few silicates (as the zeolite, harmotome), but they are all rare minerals.

Barite, or Heavy Spar. Barium sulphate, $BaSO_4$.

BARITE, the sulphate of barium, is first of all characterized by its high density, and on this account it is often called *heavy spar.* Though looking very like calcite in some varieties and feldspar in others, it is at once recognized even in a small specimen by a trained hand, for its specific gravity is 4.5, while that of the others is only 2.7.

Barite is often found in beautiful clear crystals, usually rhombic prisms or flat tabular forms. The last are often united in diverging groups like the leaves of a partly-opened book. Some of the common forms are shown in the accompanying figures; it will be seen that the "habit" varies widely. In Figs. 237, 238, 239, 245 the form is tabular, parallel to the basal plane (of perfect cleavage); in Figs. 237, 238 the fundamental or cleavage prism (m) is developed and crystals occur which are elongated in this, the vertical, direction; in Figs. 240 to 244 the habit is prismatic, but for Figs. 240, 242, 244 in the direction of one lateral axis and for Figs. 241, 243 in that of the other. It will be understood that Figs. 240, 242 show the same form, and

237.



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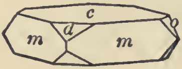

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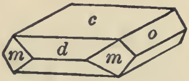

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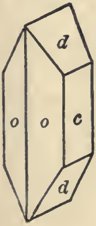

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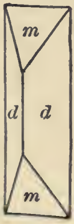

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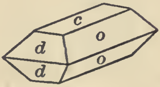

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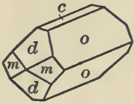

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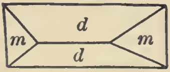

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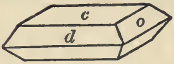


also Figs. 241 and 243, but in different positions, the second in each case corresponding to that of Figs. 237, 238.

The angle of the prism *m* (front edge) is 101½°; the angles of *d* and *o* (side edges, Fig. 239) are 77¾° and 105½°; while the angle *cd* is 141° and *co* is 127¼°.

Barite, as already intimated, has cleavage parallel to three faces, two of these (*m*) making with each other angles of about 101½° and 78½° and the other (*c*) at right angles to each of these; parallel to the last cleavage face (*c*) the crystals often show pearly luster. The form yielded by the cleavage is shown in Fig. 237. Barite is also found in cleavable masses, and in lamellar to granular compact and earthy forms which show no cleavage. The last often have a variety of colors and make a handsome marble when polished; banded kinds resembling stalagmite occur. There are also granular forms looking like statuary marble, and fibrous kinds. The hardness is 2.5 to 3.5, and the specific gravity 4.3 to 4.6. The luster is usually vitreous, though often pearly on *c* as above stated.

The formula is $BaSO_4$, which gives the percentage composition: Sulphur trioxide (SO_3) 34.3, baryta (BaO) 65.7 = 100. Barite fuses (see p. 131) in the forceps rather easily and gives the pale yellowish-green flame characteristic of barium; the fused mass when (after cooling) it is placed on a piece of moistened turmeric-paper colors it reddish brown. Fused with sodium carbonate on charcoal it reacts for sulphur (p. 146). It is insoluble in acids.

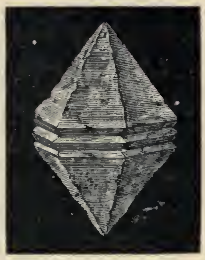
Barite is a common mineral, especially in certain mining regions, as those of England, in Cornwall, Cumberland, Derbyshire; also in Saxony, Hungary, and in Colorado.

It is often the gangue mineral of lead, copper, and other ores. It also forms veins in certain rocks, as sandstone at Cheshire, Conn. It is used extensively as a pigment, or rather an adulterant of white lead; also to glaze paper. Barium salts are also used for the colored fire at the theater.

Witherite. Barium carbonate, $BaCO_3$.

WITHERITE, the carbonate of barium, is a much less common mineral than barite, but like it it has a high specific gravity. It sometimes occurs in crystals, which may have the form of six-sided pyramids, a little suggesting quartz in aspect (Fig. 246); these crystals, however, are complex forms due to the combination or twinning of several crystals. The more common form of witherite is that in fibrous masses. The hardness is about 3.5, and the specific gravity 4.3. The luster is vitreous, inclining to resinous on fracture surfaces, and the color white, pale yellowish or grayish.

246.



The composition, $BaCO_3$, gives: Carbon dioxide (CO_2) 22.3, baryta (BaO) $77.7 = 100$. It fuses easily in the forceps and gives a yellow-green flame. In hydrochloric acid it dissolves with effervescence, the solution yielding a heavy white precipitate (barium sulphate) if a little sulphuric acid is added. Witherite is used in the refining of sugar.

BARYTO-CALCITE is a rather rare carbonate of barium and calcium occurring in white or yellowish monoclinic crystals; also in massive forms.

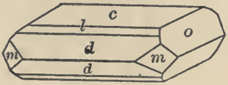
STRONTIUM.

STRONTIUM is the metal which is present in the various salts characterized by the beautiful red color which they give to the flame. The nitrate is thus used in fireworks and red fire; the hydrate is used for preparing and refining beet-sugar and in extracting crystallized sugar from molasses. The common minerals containing strontium are the sulphate, celestite, and the carbonate, strontianite; it is also present in a few silicates.

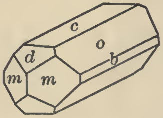
Celestite. Strontium sulphate, $SrSO_4$.

CELESTITE is a mineral closely related to barite in appearance, in fact so closely related that they often cannot be certainly told apart without a blowpipe test to show the color of the flame. It is found in crystals which, like those of barite, are sometimes flat tables (Fig. 247), sometimes prisms, and the latter often terminated by two pairs of planes *d* and *m* (Fig. 248).

247.



248.



The angles are near those of the barium sulphate, barite, the two species being *isomorphous* as defined on p. 119. The prismatic angle *m* (front edge) is 104°, also the angles of *d* and *o* (side edge) are 79° and 104°, further the angles $cd = 140\frac{1}{2}°$, $co = 128°$, $cl = 157\frac{1}{2}°$.

The cleavage form is like that of barite; that is, the crystal cleaves parallel to *c* and *m*. There are also massive cleavable forms, and others which are finely fibrous. The hardness of celestite is 3 to 3.5, and the specific gravity 3.95 to 4. The luster is vitreous, or pearly on the face of cleavage. The color is commonly white, but the crystals often show a tinge of blue, and the same is true of the fibrous forms, and although this is not an essential character, it is so common that it has given the name to the species from the Latin *cœlestis*. There is also a red variety.

The composition of celestite, $SrSO_4$, gives: Sulphur trioxide 43.6, strontia 56.4 = 100. A fragment heated in the forceps tinges the flame a deep red and fuses at 3 to a white bead which reacts alkaline on turmeric-paper. It is insoluble in acids.

Celestite is often associated with limestone, and with gypsum, rock-salt, and clay; it also occurs in sandstone; occasionally with metallic minerals as galena and sphalerite. It is not so common a mineral as barite.

Strontianite. Strontium carbonate, $SrCO_3$.

STRONTIANITE, the carbonate of strontium, is the other important strontium mineral, though less common than celestite. It is sometimes found in prismatic crystals, occasionally transparent, but commonly in fibrous or granular masses of a white, pinkish, or greenish color. The hardness is 3.5 to 4, and the specific gravity about 3.7. The luster is vitreous, inclining to resinous on faces of fracture.

The composition $SrCO_3$ gives: Carbon dioxide (CO_2) 29.9, strontia (SrO) 70.1 = 100. Strontianite gives the same red color to the blowpipe flame as celestite, but it is at once distinguished by its effervescing in hydrochloric acid.

Sodium and Potassium.

The metals SODIUM and POTASSIUM, though obtained with some difficulty, are interesting to the chemist because they combine so eagerly with oxygen. For this reason they can be preserved only in some non-oxidizable medium, as oil, and a fragment of potassium placed in water takes fire and burns, uniting with the oxygen and liberating hydrogen; sodium also decomposes water. The rare metals cæsium and rubidium have a similar chemical character, and finally lithium, the lightest of all the metals, with a specific gravity of only half that of water.

Only a few simple compounds of sodium and potassium are known, but they both enter into the composition of very many of the complex silicates.

Of the other metals named above, cæsium and rubidium have a very limited occurrence, being known only in certain rare silicates; lithium, however, enters into the composition of lepidolite or lithia mica, rubellite or lithia tourmaline, also the rare phosphates triphylite (and related compounds), amblygonite, and a few other species.

Halite, or Rock-salt. Sodium chloride, NaCl.

HALITE, or rock-salt, is one of the few important minerals which is readily soluble in water and hence gives a decided taste. This taste is familiar to every one, for halite is simply the natural form of table-salt.

It crystallizes in fine clear cubic crystals with perfect cubic cleavage ; it is also found in granular cleavable masses. Sometimes the crystals have the skeleton or hopper shape spoken of on p. 54.

The hardness is 2.5, and the specific gravity 2.1. It has a vitreous luster, and it is colorless when perfectly pure, but from white it passes through various shades of red and yellow ; occasional patches of a fine deep blue are seen in the clear crystals.

The composition sodium chloride, $NaCl$, gives: Chlorine 39.4, sodium 60.6 = 100. The deep yellow color given to the blowpipe flame (best when fused on a platinum wire) is a very characteristic reaction. It also gives the reaction for chlorine mentioned on p. 133.

Beds of salt are common in many parts of the world, where it is mined in large quantities for commercial use. There are also salt-wells in certain regions, as in New York, Ohio and other States, the brine from which is pumped up and evaporated for the sake of the salt which it yields. Salt is also present in sea-water, being the most important of the saline substances in solution to which the peculiar taste is due, some of the others being magnesium sulphate and chloride. The ocean is hence an important source of the salt of commerce. Sodium chloride is also present still more largely in the water of some inland seas, as the Great Salt Lake in Utah, the Dead and Caspian seas, and many others. It is to the gradual evaporation of bodies of salt water that we must look for the explanation of the beds of salt the occurrence of which has been alluded to.

Borax, the sodium borate which is so familiar to one who works with the blowpipe (see p. 125), also occurs in nature, and on so large a scale in certain limited regions as to be extensively mined. It is found in monoclinic crystals, often of large size; they are clear at first, but lose water on exposure and become white and opaque. Borax Lake in Lake County, California, as also another lake of the same name in San Bernardino County, affords this mineral; there are also large deposits in Tibet. Borax finds many uses in the arts, as in making glass and soap, in soldering, in medicine, etc.

Some other sodium compounds occurring in nature are the carbonates, including natron and trona; the fluoride, cryolite, already described on p. 242; the nitrate, called soda-niter; the sulphates, thenardite and mirabilite (glauber salt), further, glauberite (containing also lime). Sodium is also present in many silicates, as albite, natrolite, etc.

Sylvite, or the chloride of potassium (KCl), is a rare mineral occasionally found associated with halite or rock-salt, and closely resembling it in form, taste, and other characters. It is easily distinguished by the violet color which it gives the blowpipe flame.

Potassium also forms a number of compounds, as sulphates, borates, etc., but they are mostly rare and hardly to be found in the cabinet of most mineralogists. It also enters into the composition of many silicates, as, for example, orthoclase or potash feldspar, also muscovite or common potash mica. So, too, apophyllite and many others.

A few minerals, interesting because they contain rare elements, may be mentioned briefly in this place.

MONAZITE is the most important of these. It is essentially a phosphate of cerium and the allied elements lanthanum and didymium, but contains also varying quantities of thorium. It is to this last element that it owes its importance, since the oxide, thoria or thorina, is used in the preparation of the common form of gas-burner, in which the light is given by the incandescence of a delicate hood suspended in the flame. Monazite was so named because of its rarity (from *μονάζειν, to be solitary*), being discovered in small isolated monoclinic crystals imbedded in certain rocks, as gneiss. It has, however, since been found in large quantities as a rock constituent, and where, as, for example, in North Carolina, the rock has been disintegrated by the weather, it is possible to separate it and obtain it in large quantities. The crystals have sometimes a brilliant luster, and vary in color from reddish to yellowish brown; hardness 5 to 5.5; specific gravity 5 to 5.2. It is also found in Norway, Russia, and Brazil; *turnerite* is a variety found in Switzerland.

XENOTIME is a phosphate of yttrium and other rare elements; it occurs in tetragonal crystals resembling those of zircon in form and angles (see p. 312). It occurs sparingly in granitic and gneissoid rocks.

PYROCHLORE is a rare mineral containing niobium, thorium, titanium, also, as bases, calcium, cerium, sodium; it is found in octahedral crystals of a brown color in Norway and in the Ural.

MICROLITE, related to pyrochlore, is essentially a calcium tantalate. It occurs in octahedral crystals, usually very small (whence the name), and often imbedded in albite, as at Chesterfield, Mass.; also in larger complex forms (Fig. 30, p. 28), as in Amelia County, Virginia.

SILICON.

SILICON is, next to oxygen, the most widely distributed of the chemical elements; in fact it is estimated to make up about one fourth of the earth's crust. The element itself is known only to the chemist, who obtains it with some difficulty from its compounds; one form is that of reddish crystals, resembling those of the diamond and almost as hard.

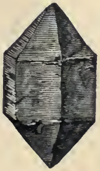
The common compound of silicon in nature is the oxide, SiO_2, called usually simply silica. The well-known mineral quartz has this composition. Opal is another kind of silica, amorphous and containing some water. There is also a rare form found in some volcanic rocks in thin transparent hexagonal plates; this is the mineral TRIDYMITE.

Silica is present as the acid part of a large family of compounds, called SILICATES, which includes not only a greater number of minerals than any other family, but also some of the commonest and most beautiful of species. The feldspars, micas, zeolites, also garnet, beryl, amphibole or hornblende, pyroxene, and topaz are all silicates, and there are many others which will be mentioned in the pages which follow.

Quartz. Silicon dioxide, SiO_2.

QUARTZ, the oxide of silicon, is the commonest of minerals, and in some of its varieties one of the most beautiful. It makes up most of the sand of the seashore; it occurs as a rock in the forms of sandstone and quartzite, and is a prominent part of many other important rocks, as granite and gneiss. It is a mineral which can be usually recognized by its form when crystallized; also by its hardness, conchoidal fracture, its glassy luster and infusibility. There are so many varieties, however, that it is only after long practice that one can be sure of always identifying it at once.

249.



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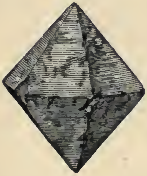

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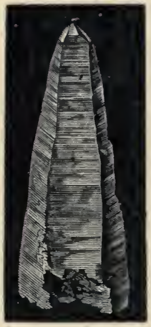

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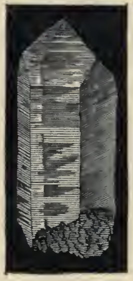

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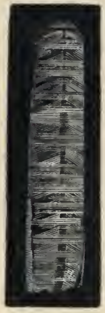
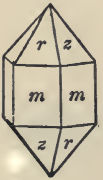


The common form of quartz crystals is that of a hexagonal prism terminated by six pyramidal planes each having the shape of an acute isosceles triangle (Figs. 249 and 254). Sometimes the prism is entirely wanting, and then the form is like that of Figs. 250 and 255, which is a double hexagonal pyramid, or *quartzoid*. It is not uncommon to find three of these pyramidal faces—every other one, those lettered *r* in Fig. 254—much larger than the others; or they may be present alone (Figs. 252, 253, also 256 to 259). It is because of this fact and for other reasons that it is concluded that these three planes, lettered *r*, with those corresponding to them at the other end of the crystal, belong together and are different from the subordinate set (lettered *z*). These six planes (*r*) form a rhombohedron not very far from a cube in angle (see Fig. 257), and hence the fundamental form is said to be *rhombohedral* instead of hexagonal.

254.



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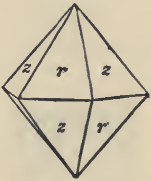

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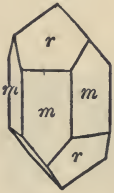

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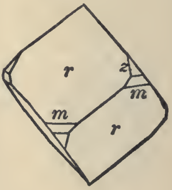

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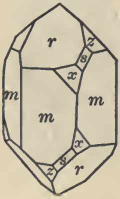

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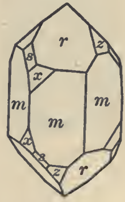

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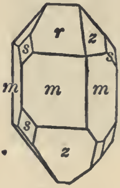

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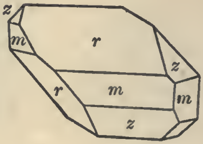


Further, when the smaller modifying planes on a quartz crystal are studied—and the crystals are sometimes very complex—or when the molecular structure is investigated by the etching process already described (see p. 64 and Fig. 132), or by the method of pyro-electricity (p. 97), it is found that this structure is highly intricate. This is a matter, indeed, for the skilled mineralogist, but even a beginner may learn to recognize, for example, on a Swiss crystal of smoky quartz the difference between the forms shown in Figs. 258 and 259. The first, which is called a *right handed* crystal, has the little planes, like that lettered x, to the *right* above the prismatic face m, which is below the face r (usually identified by being larger than z); while the other is a *left-handed* crystal and has such a plane to the *left* above m. With this difference goes also a more important distinction in optical character which it is for the advanced student in mineralogy to learn about.

The important angles between the faces are as follows:

$rr' =$ 94° 14′ and 85° 46′ (Figs. 256, 257);
$rz =$ 133° 44′ (over the terminal edge),
103° 34′ (horizontal edge);
$mr =$ 141° 47′ (horizontal edge, Fig. 254);
$ms =$ 142° 2′ (Fig. 258).

The difficulty in deciphering even simple crystals of quartz is much increased by the fact that very commonly they are much distorted; that is, some faces are larger than in the ideal figure and others smaller, so that the form may be like that of Fig. 260 or 261; other still more irregular crystals are not uncommon. In all, these cases, however, the angles remain the same without change, notwithstanding the seeming irregularity in the form. In trying to put such a crystal into its proper position, it may be remembered that the prismatic faces are almost always finely lined, or striated, in a horizontal direction (see Fig. 3, p. 15).

Though crystals like those shown in Figs. 249, 250, having both extremities complete, sometimes occur, it is much more common to find the prisms attached at one end and only the other end freely developed, as shown in Figs. 251 to 253; further, the crystals may be slender and tapering as in Fig. 251. Not infrequently the crystals are so small over a surface that their form can be distinguished only by a magnifying-glass, and the surface is rough and *drusy*. There are also many massive kinds of quartz, as mentioned in subsequent paragraphs.

Twin crystals of quartz of the ordinary type, as Fig. 125, p. 60, are not often found; the grouping is usually quite irregular. At the same time it is common to find by careful study of the small modifying planes, by examination in polarized light or other means, that a crystal of quartz, appearing at first sight simple, is really made up of two crystals in twinning position interpenetrating each other very irregularly. Sometimes this is indicated by the difference in luster, or the striations, of parts of the surface of the prismatic and pyramidal planes; this is true, for example, with many of the crystals of smoky quartz from the Pike's Peak region in Colorado.

The hardness of quartz is 7, so that it cannot be scratched by a knife, while it easily scratches glass; the specific gravity of pure crystals is 2.66. The luster of quartz crystals is vitreous or glassy; some massive kinds are greasy and others waxy; while the impure kinds, like jasper, are dull. The color varies widely; crystals are usually colorless or nearly so, but also yellow and brown to nearly black; there are also pink, green, and red kinds. The massive forms vary still more, and the color is often in bands or clouds, as described under the varieties below.

Quartz appears under a great number of varieties, differing particularly in color and structure, and as many have long been used for ornamental purposes, they have received a number of distinct names. The crystalline varieties are named chiefly according to their color; they include:

Rock-crystal, the clear colorless variety; when quite free from flaws it is used for spectacle-glasses (as the Brazilian pebble). The Japanese make beautiful crystal spheres of rock-crystal.

Smoky quartz, having a smoky brown color, sometimes very dark. It is cut into ornaments, as in Switzerland, where it is found in beautiful specimens. In Scotland it is called *cairngorm stone.*

Amethyst, a fine purple kind, also used for ornaments. A yellow variety of quartz crystal is called *false topaz.*

The small rock-crystals are so bright that they are often called diamonds, though really far inferior to the diamond in luster and brilliancy. *Lake George diamonds, Bristol diamonds,* and other like names have been given to such crystals of quartz.

Besides the distinct crystals, the massive quartz is sometimes clear as crystal, and is then called, like the crystals themselves, *rock-crystal.* It is also sometimes cloudy; or again milky white, then called *milk-quartz;* or rose-colored, in *rose-quartz*. Further, *aventurine quartz* is a kind spangled with scales of hematite (or goethite) or mica. *Cat's-eye* may be mentioned here, though in part chalcedony; it is a kind giving when polished a peculiar effect of opalescence, usually due to fibers of asbestus, which somewhat resembles the reflection from the eye of a cat. The same name is given to other stones having like effects; the highly-prized cat's-eye of jewelry is a variety of chrysoberyl (p. 242). *Tiger-eye* is a siliceous stone, usually of a yellow color and somewhat like cat's-eye in effect; this is due to the fibrous structure of the original mineral (crocidolite) from which it has been formed (see p. 298).

262.

Chalcedony.

263.

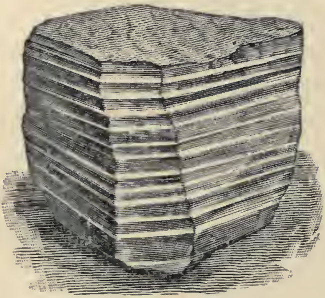
Agate.

The imperfectly crystalline, or cryptocrystalline, kinds of quartz are also numerous and include many valued ornamental stones.

Chalcedony is a kind having a waxy luster, either transparent or translucent, and varying in color from white to gray, blue, brown, and other shades; it often has a mammillary, botryoidal, or stalactitic structure (Fig. 262, also Fig. 137, p. 68).

Agate is a variegated chalcedony, commonly with the colors arranged in delicate parallel bands, straight, curved, or zigzag. These lines often follow the irregular outline of the cavity in which the silica was deposited, and hence show the successive layers formed (Fig. 263). The colors may be also in irregular clouds, as in *clouded* agate. *Moss-agate* is a kind of chalcedony, or it may be rock-crystal, containing brown or black mosslike or dendritic forms distributed rather thickly through the mass; these consist of some metallic oxide (as of manganese), and have nothing more to do with vegetation than the frost figures on a window-pane in winter. Another kind of agate is the *ruin* or *fortification agate.*

264.



Onyx.

Carnelian is a red or brownish-red chalcedony; sard is essentially the same stone.

Onyx is, like much agate, made up of layers of different colors, usually white and black or white and brown, but the banding is straight and the layers are in even planes.

The stones may hence be used for cameos, the head being cut from one layer and the background formed by the other. Both the varieties agate and onyx are often artificially colored in order to make them more attractive for ornaments.

Sardonyx is like onyx, but has layers of sard (carnelian) with others which are white or black. *Prase* is a translucent leek-green chalcedony, *chrysoprase* an apple-green chalcedony. *Heliotrope,* or blood-stone, is green (like the kind called plasma) with spots of red jasper looking a little like drops of blood.

The varieties of quartz which follow are all more or less impure; their luster is dull, and they are in many cases nearly or quite opaque.

Jasper is an impure opaque colored quartz, often red (colored by red iron sesquioxide), also brown or ocher-yellow and dark green. Sometimes the red and green colors are shown in the same specimen, arranged in bands as in riband jasper.

Flint is nearly opaque and has a dull color, usually gray, smoky brown, and brownish black. The exterior is often whitish, from mixture with lime or chalk, in which it is imbedded, as in the chalk formation; luster barely glistening, subvitreous. It breaks with a deeply conchoidal fracture and a sharp cutting edge, and is hence easily chipped, as by the Indians, into arrow-heads or hatchets. *Hornstone* resembles flint, but is more brittle, and the fracture more splintery. *Chert* is a term often applied to hornstone, and to any impure flinty rock.

Basanite, Lydian Stone, or *Touchstone* is a velvet-black flintlike stone used on account of its hardness and black color for trying the purity of gold. The color left on the stone after rubbing the metal across it indicates the amount of alloy. It is not splintery like hornstone.

Silicified wood consists largely of chalcedony, agate, or jasper, which has replaced the woody structure of the tree; it may vary much in color and thus give beautiful effects when polished, as is true of the much-used kinds from the "petrified forest" near Holbrook, Arizona. Cavities often contain crystals of quartz. Some silicified wood properly belongs to the species opal.

Quartz, as already stated, is the oxide of silicon, or silicon dioxide, SiO_2. It is infusible before the blowpipe alone; it dissolves slowly in a borax bead and with effervescence in a bead of sodium carbonate. It is insoluble in acids.

Quartz occurs as one of the essential constituents of granite, syenite, gneiss, mica schist, and many related rocks; as the principal constituent of quartz-rock and many sandstones; as an unessential ingredient in some trachyte, porphyry, etc.; as the vein-stone in various rocks, and for a large part of mineral veins; as a foreign mineral in the cavities of trap, basalt, and related rocks, some limestones, etc., making geodes of crystals, or of chalcedony, agate, carnelian, etc.; as imbedded nodules or masses in various limestones, constituting the flint of the chalk formation, the hornstone of other limestones—these nodules sometimes becoming continuous layers; as masses of jasper occasionally in limestone. It is the principal material of the pebbles of gravel-beds, and of the sands of the seashore and sand-beds everywhere. The famous localities are so numerous that it would be impossible to mention even a small part of them. The finest specimens usually come from cavities in granite and related rocks as in Switzerland. North Carolina and Colorado afford beautiful and complex crystals.

Some of the uses of the various varieties of quartz have been alluded to; most of them are in the way of ornaments or ornamental stones. Besides this, quartz-sand is used for sandpaper and in making glass and porcelain; blocks of quartzite are employed for hearthstones.

Opal

OPAL is a form of silica containing a few per cent of water. It does not occur in crystals, but in massive and amorphous forms only; these often show a peculiar effect called *opalescence,* like that of water containing a few drops of milk, and some varieties show a beautiful play of color.

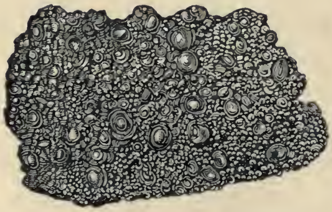
The hardness is about 6, a little less than that of quartz, and the specific gravity is also less, or only about 2. The color varies from white to yellow, red, brown, green, gray, and black. It is sometimes transparent, but more commonly only translucent. It is soluble in caustic alkalies, which is not true of crystallized quartz.

The most beautiful variety of opal is that called *precious opal,* much admired because of the delicate play of colors, due to the optical effect of internal reflections; the colors are often seen on a white, also on a red, ground. One kind of precious opal with a bright red flash of light is called the *fire-opal,* and another kind is the *harlequin-opal.* A beautiful opal found in Queensland shows an iridescent blue sometimes like the effect of a peacock's wing.

Common opal does not exhibit this play of colors, and it varies widely in color and appearance. *Milk-opal* is one kind, which has a pure white color and milky opalescence; while *resin-opal* or *wax-opal* has a waxy luster and yellow color. *Jasper-opal* is intermediate between jasper and opal. *Wood-opal* is petrified wood in which the mineral material is opal instead of quartz. *Hyalite* or Müller's glass is a kind of opal in clear glassy globular forms looking like drops of gum.

The silica deposited from hot springs, as by the geysers of the Yellowstone Park and those of New Zealand, is a kind of opal and is called *geyserite* or siliceous sinter (Fig. 265).

265.



It is usually white or gray in color, translucent or opaque, and often with a pearly luster on the surface. The form is varied and sometimes very beautiful. *Infusorial earth* is a kind of opal-silica consisting of the microscopic shells of the minute vegetable organisms called diatoms, and as found in beds sometimes of great extent is properly ranked as a mineral and a variety of opal; electro-silicon is the trade name of one kind much used for polishing silver: the siliceous shells are so fine that they do not scratch the surface. A layer of pure white infusorial earth is often found under a peat-bed; it would not be easy to estimate the enormous number of the diatom shells that would be required to make up a cubic inch of it.

Opal is commonly met with in seams of certain volcanic rocks; it sometimes occurs in limestone and also in metallic veins. The Yellowstone Park is a famous locality for the kind called *geyserite.*

SILICATES.

The silicates, as has already been remarked (see pp. 113, 272), form a very large class of minerals, in which silicon is present as the acid element, and various metals, sometimes iron, manganese, zinc, copper, but more often aluminium, calcium, magnesium, sodium, potassium, are the bases. As many of the silicates contain two or more of the bases it is more convenient to treat them here together than to try to separate them under the heads of the metals present; moreover, very few of them are economically useful as ores of the metals which they contain: a few of these have already been included in the preceding pages.

THE FELDSPARS.

The FELDSPARS form the most important group among the silicates. They are found in large masses in what are called granite veins—aggregations of feldspar with quartz and mica filling veins in the enclosing rock. They are also an essential part of nearly all the common kinds of crystalline rocks, as granite, syenite, gneiss, also basalt, trachyte, and others. They are all silicates of alumina with either potash, soda, lime, or rarely baryta.

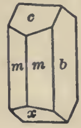
The feldspars include several different species. Of these, *orthoclase*, or potash feldspar, is the most common; *albite*, or soda feldspar, is also common, while the lime feldspar, *anorthite*, is rare, more so, indeed, than the intermediate kinds, *oligoclase* and *labradorite*, both of which are soda-lime feldspars. There is also a kind of feldspar called *hyalophane*, which is a baryta feldspar, but too rare to be more than mentioned here.

All the feldspars occur in crystals which have a certain general resemblance to each other, although, while orthoclase is monoclinic, albite, anorthite, oligoclose, and labradorite are triclinic. They all have cleavage in two directions making angles of 90,° or nealy 90,° with each other; hence rectangular cleavage masses are very common; a little attention, however, shows that the two directions are unlike, that is, cleavage is easier parallel to one face than to the other. They have a hardness about 6, so that they are not scratched by a knife. The specific gravity lies between 2.5 and 2.7, or is not far from that of quartz; only for hyalophane is the specific gravity as high as 2.8. The color is usually not far from white, and pale yellowish, reddish, or greenish shades are common, while dark colors are rare.

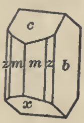
Orthoclase. Potash Feldspar, $KAlSi_3O_8$.

ORTHOCLASE, or potash feldspar, is the commonest and most valuable species of the group; it is the feldspar of granite and granite veins, gneiss, syenite, and many other rocks. The name is from two Greek words (ὀρϑός, *erect*, and κλάσις, *fracture*), referring to the existence of the two prominent cleavages at *right angles* to each other.

266.



267.



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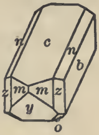

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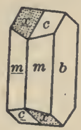

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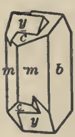
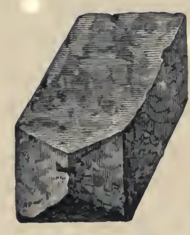


These cleavages are parallel to the top or basal plane (*c*) and to the side plane (*b*) of the crystals, as shown in the figures (266 to 270). These figures represent the common forms: a prism of nearly 120° (lettered *m*), the faces of which are sometimes quite short (Figs. 268, 271); a basal plane (*c*) inclined 116° to the front edge of this prism, and another plane or two planes below (and behind) lettered *x* and *y*; the angle between *c* and *x* is 129° 44′, and between *c* and *y* is 99° 42′; also *x* is inclined 114¼° to the front edge of *m*, and *y* 144¼° to this edge. There may also be various other modifying planes, as a pyramid *o* (Fig. 268), a prism *z* (Figs. 267, 268), a dome *n* inclined about 135° to *c* (Fig. 268).

271.



Twin crystals are very common, especially of the kind shown in Figs. 269, 270, called *Carlsbad twins*, because found at Carlsbad, Bohemia; notice that Fig. 269 looks like a simple crystal, and it is only by carefully observing the fact that the cleavage exists parallel only to one half of the end face above and below (the parts lettered *c*) that the compound character is proved. Here the faces *c* and *x* of the two half-crystals in the twinned position almost coincide because each makes nearly the same angle with the front edge of *m*. Orthoclase is also found in masses, sometimes very large, usually showing very distinctly the two cleavages which have been mentioned; there are kinds, however, which are close and compact like porcelain.

The hardness of orthoclase is 6, and the specific gravity about 2.6; the hardness is the commonest test by which it is distinguished from calcite and barite, while it is also much less dense than barite. The luster is vitreous, though sometimes pearly on the basal cleavage surface; it is sometimes clear and colorless, but commonly it is white or reddish, or pale yellow.

The clear, glassy variety found in the Alps is called *adularia*, while *sanidine* is a glassy kind found in crystals imbedded in lava and various volcanic rocks; *moonstone* is a kind giving a beautiful bluish opalescence, especially when polished, and hence used for pins and other ornaments; the best is found in Ceylon; some moonstone also belongs to the species albite. The formula of orthoclase is stated above, $KAlS_3O_8$ or $K_2O.Al_2O_3.6SiO_2$, which gives the percentage composition: Silica (SiO_2) 64.7, alumina (Al_2O_3) 18.4, potash (K_2O) 16.9 = 100. It fuses on thin edges with some difficulty; it is not attacked by acids. On the method required to show the presence of potash see p. 134.

Orthoclase, as has been mentioned, is the common feldspar of granite, gneiss, and related rocks; it is present sometimes in large masses in granite veins, as in the New

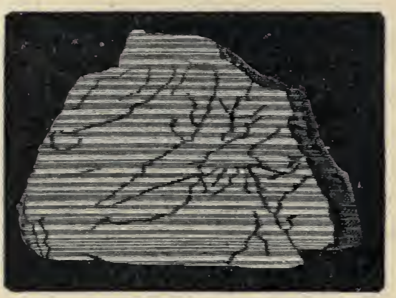
England States, also North Carolina and elsewhere. In the latter case it is often possible to obtain it in considerable quantity free from the associated quartz and mica, and it is then mined and used in the making of porcelain. In cavities in these rocks fine crystals can frequently be found. Associated with the orthoclase feldspar in the granite veins is commonly the soda feldspar, albite; also often many interesting minerals, as tourmaline (sometimes the rare red and green kinds), beryl, apatite, the rarer species columbite, cassiterite, chrysoberyl, spodumene, and many others.

There is also another kind of potash feldspar, like orthoclase in composition, but distinguished by optical examination under the microscope as a triclinic species; the angle between the two cleavage surfaces differs a very little from 90°. This kind is called MICROCLINE, and includes the beautiful bluish-green potash feldspar called *amazon-stone* from near Pike's Peak in Colorado, in Siberia, and elsewhere. The distinction between orthoclase and microcline, however, is one which only a skilled mineralogist can note, or, perhaps, is bound to regard.

Albite. Soda Feldspar, $NaAlSi_3O_8$.

ALBITE, or soda feldspar, takes its name from the Latin *albus,* meaning white, referring to the fact of the common color. It occurs in crystals which are somewhat like orthoclase in angles, although belonging to the triclinic system (see Fig. 99, p. 46). The crystals, however, are seldom distinct and easy to decipher. Usually they are small, flattened in one direction and crowded together in parallel lines or ridges, a little resembling barite (p. 262). Much albite is simply massive, and then the cleavage surface parallel to the base commonly shows a series of fine lines or ridges which catch the light when the specimen is held so as to reflect it (Fig. 272). These are due to a kind of twinning (explained on p. 59), in which the parts of the crystal are in thin parallel plates alternately repeated in the twinned position. This kind of twinning is common in all the triclinic feldspars, called in general *plagioclase,** in which the two cleavages are inclined a few degrees from the 90° angle characteristic of orthoclase. The massive albite has often a wavy surface, so that the directions of cleavage are more or less concealed.

272.



The hardness of albite is 6 to 6.5, and the specific gravity about 2.62. The luster is vitreous or pearly, and the color, besides the common white, also bluish, gray, reddish, greenish; the crystals are often clear and glassy.

The formula $NaAlSi_3O_8$ or $Na_2O.Al_2O_3.6SiO_2$ gives the percentage composition: Silica (SiO_2) 68.7, alumina (Al_2O)

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* From the Greek πλάγιος, *oblique,* and κλάσις, *fracture.*

19.05, soda (Na_2O) 11.8 = 100. Albite fuses without much difficulty (more easily than orthoclase) and colors the flame yellow. It is not attacked by acids.

Albite is present in many crystalline rocks, particularly in granite and in granite veins, where it occurs with the potash feldspar, orthoclase; from this source it is often obtained in fine groups of crystals in cavities, while the massive kinds often enclose some of the rare species mentioned on p. 288.

Anorthite. Lime Feldspar, $CaAl_2Si_2O_8$.

ANORTHITE, or lime feldspar, is a rare species, and the best crystals occur in the volcanic rocks of Vesuvius. It is also found in massive forms, but they can be identified only by minute optical examination or by analysis.

Anorthite is interesting because it forms one end of a series, at the other end of which is albite, or soda feldspar, and which includes a number of intermediate species containing both soda and lime, or soda-lime feldspars. The full understanding of this subject belongs to the higher study of mineralogy, but it will be easily remembered that between the pure soda feldspar, albite, with 68.7 per cent of silica (SiO_2), and the pure lime feldspar, anorthite, with 43.2 per cent SiO_2, there are intermediate kinds varying in the amount of soda and lime. Those near anorthite have less silica and less soda, and those near albite relatively more of both. The two most important of the intermediate kinds are *oligoclase* and *labradorite*. OLIGOCLASE is a soda-lime feldspar, while labradorite is rather a lime-soda feldspar. Oligoclase is seldom in distinct crystals, and the massive kinds can be identified only by chemical analysis or by careful optical study.

LABRADORITE is also rare in crystals, but it is particularly interesting because it often shows a beautiful play of colors in certain directions, which is due to the optical effect of a multitude of minute plates of foreign species inclosed in the specimen and which are seen when a thin section is examined under the microscope. The finest labradorite was brought to Europe from Labrador by a missionary in 1770 and was then called *Labrador feldspar*. The best specimens still come from the same source, but many of the rocks of the Adirondack region consist largely of labradorite and pretty specimens may be occasionally found.

The following species are allied to the feldspars in the way in which they occur in certain rocks:

LEUCITE is a silicate of alumina and potash crystallizing usually in trapezohedrons, like the common form of garnet (Fig. 285, p. 300). The color is white; luster vitreous; hardness 5.5 to 6; specific gravity 2.5.

SODALITE is a silicate of alumina and soda, containing also chlorine. It belongs to the isometric system, but is usually found in massive forms varying in color from white to gray, yellow, or blue. Hardness 5.5 to 6; specific gravity 2.3.

LAPIS-LAZULI is a mineral of a beautiful blue color, and hence often used as an ornamental stone; the artificial *ultramarine* is similar. It is a silicate of alumina, lime, and soda, containing also some sulphur trioxide (SO_3).

NEPHELITE is a silicate of alumina, soda, and potash occurring in glassy hexagonal crystals and in massive forms or a gray to green or red color and with greasy luster (the variety *elæolite*). Hardness 5.5 to 6; specific gravity 2.6. It is common in igneous rocks.

CANCRINITE is related to nephelite, but yields also carbon dioxide (CO_2) and water, its composition being rather complex. Massive forms of a yellow color are most common. Hardness 5 to 6; specific gravity 2.45.

Pyroxene.

PYROXENE is one of the most important of the silicates, and at the same time often one of the most difficult to recognize. This is largely because it appears in a great variety of forms, and of many of these the characters may not be very distinct.

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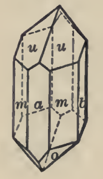

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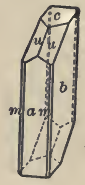

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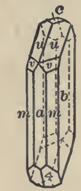

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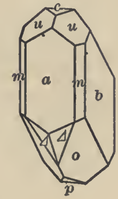

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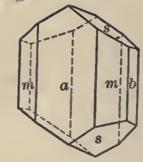


It crystallizes in oblique rhombic prisms (*m*), having an angle in front (*m* on *m* over *a*) of 87° and on the side (over *b*) of 93°. If *a* and *b* are small or absent, a crystal looks at first sight like a square prism and may be mistaken for this if the end planes are broken off or indistinct. On the other hand, if the faces of the prism, *m*, are small or absent, the pinacoid planes *a* and *b* being prominent (as in Fig. 274, and Fig. 93 on p. 45), the resemblance to a square prism is even more striking, since *a* and *b* actually make angles of 90° with each other. Here also the monoclinic symmetry in the distribution of the terminal planes is decisive. For when these planes (*u*, *v*, etc.) are distinct, it is easy to see that the like faces are present only two and two, not four at each end, and also that the basal plane *c* is oblique to the face *a* and to the prismatic edge, not at right angles to them. Parallel to this plane *c* the crystal often separates into thin layers, and the oblique lines showing this structure can often be seen on the vertical faces.

The angle of the prism *m* in front is 87°, as already stated, while *c* is inclined 105° 50′ to the front edge of this prism or to the face *a*; the angle between two faces *u* is 131½°; of *o* 95°; and of *s* 121°. See Figs. 273 to 277, also Figs. 93, 96, p. 45.

The hardness of pyroxene is 5.5 to 6, and the specific gravity varies between 3.2 and 3.5. The luster is vitreous and often dull, and the color is usually a dingy gray or green to black; there are rare kinds which are transparent and nearly colorless, also white varieties, and others that are bright green and even pink, but these last are less common.

The nearly colorless, white, or very pale green kind of pyroxene—usually called *diopside*—is a silicate of lime and magnesia and has the formula $CaMgSi_2O_6$ or $CaO.MgO.2SiO_2$. There is also a rather rare black kind that contains lime and iron, and another, more common, containing lime, magnesia, and iron, which has usually a grayish green or dark green color. *Salite* belongs here; it often shows a lamellar structure parallel to the basal plane (*c*).

Diallage is a thin foliated variety of pyroxene of a green color. *Coccolite* is about the same as salite in composition, but occurs in grains easily separated from each other; they are often imbedded in crystalline limestone. It is named from the Greek κόκκος, a *grain.*

There are also some important kinds of pyroxene which contain alumina, but not in very large amount, and the commonest of these is called *augite.* This is greenish black or brownish black in color, or even quite black; the specific gravity is about 3.3; it contains silica, lime, magnesia, and iron, as well as some alumina. This is the common pyroxene of eruptive rocks, like basalt and diabase, to which belong the trap rocks of the Palisades on the Hudson and many localities in Connecticut, Massachusetts, and elsewhere.

All the varieties of pyroxene, except those last mentioned containing alumina, have the general formula of a metasilicate, $RSiO_3$, in which R represents calcium, magnesium, also iron and manganese. Most kinds of pyroxene fuse in the blowpipe flame without great trouble; the dark-colored kinds give a magnetic bead, from the presence of iron.

Pyroxene is a common mineral in crystalline limestone and dolomite, especially the white and light-colored kinds; also in serpentine and in various types of volcanic rocks. It is curious to note that the name (from πῦρ, *fire,* and ξένος, *stranger*) early given by a French mineralogist recorded his idea that it was "a stranger in the domain of fire," while in fact exactly the reverse is true. Some of the best localities for crystals of pyroxene are in the northern part of the State of New York; also at many points in Canada.

Enstatite and **Hypersthene** are minerals related to pyroxene in form and composition, but crystallizing in the orthorhombic system. Enstatite is a silicate of magnesia with but little iron, while hypersthene contains iron in a larger amount. Hypersthene is especially interesting because some varieties show a peculiar almost metallic luster in certain directions, due to internal reflections from enclosed microscopic scales of a foreign mineral. *Bronzite* is a variety of enstatite containing more iron than the other kinds; it is fusible with difficulty in very thin splinters, while the magnesian enstatite is nearly infusible. The alteration of enstatite at Edwards, New York, has yielded the fibrous talc alluded to on a subsequent page.

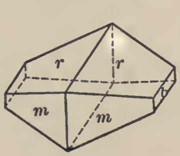
Spodumene is a rather rare mineral also related to pyroxene, interesting as being a silicate of alumina and lithia ($LiAlSi_2O_6$ or $Li_2O.Al_2O_3.4SiO_2$). It occurs usually in white, grayish, or yellowish prismatic crystals, sometimes of enormous size (even up to four feet or more in length), as at Chesterfield, Mass., and Branchville, Conn. It is also rarely a fine purple, and the most beautiful variety (called *hiddenite*), occurring in small crystals of a fine emerald-green, has been used as a gem; this kind is found in North Carolina. Spodumene fuses before the blowpipe at 3.5 and gives a fine purple-red color to the flame.

Wollastonite, a silicate of lime, is also related to pyroxene with the formula $CaSiO_3$. It is usually found in white cleavable fragments, showing a fibrous structure, also in flat monoclinic crystals, whence it is sometimes called *tabular spar.*

Amphibole.

AMPHIBOLE is a mineral which in many respects is closely related to pyroxene, both as regards form and composition; it resembles it further in the common green and gray shades of color. It also occurs in monoclinic crystals, but these show perfect cleavage parallel to the faces of the prism (m), which make an angle in front of 124½°. The crystals are very often terminated by two planes oblique to the prismatic edge and making a large angle with one another ($rr = 148\frac{1}{2}°$, Figs. 278–280). The form of the crystals and the large angle of prismatic cleavage serve to distinguish them from crystals of pyroxene.

278.



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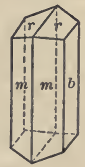

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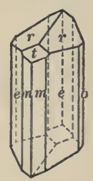

Besides the crystals, it is common to find amphibole in columnar and bladed forms, which, however, still show the prismatic cleavage to the skilled observer, and, as forms like these are rare with pyroxene, this serves to aid in distinguishing the two species. Further, it may be coarse to fine fibrous, and in the latter case look like flax.

The hardness is 5 to 6, and the specific gravity varies from 2.9 to 3.4. The luster is vitreous, or pearly in the fibrous kinds. The color varies from white to gray, green of many shades, and black, also occasionally pink. Some kinds phosphoresce, or give out light, as when two pieces are rubbed together in the dark.

The common varieties correspond pretty closely to those of pyroxene. *Tremolite* is a silicate of lime and magnesia free from iron, and is white in color, or very pale green, like the related diopside. *Actinolite* is green, and besides lime and magnesia contains also iron; it is often in fibrous or columnar masses, sometimes with a radiated structure. *Nephrite,* including much of the green Oriental jade, is a closely compact variety of actinolite; the whitish varieties of nephrite, however, approach nearer to tremolite. Another kind of jade is a different mineral, though having the same appearance; it is a silicate of alumina and *soda,* related to pyroxene, and is called *jadeite.*

*Asbestus** is a variety usually like actinolite in composition, but separable into very fine flexible fibers, which may be made or woven into an incombustible paper or cloth. *Mountain leather* is a curious kind, in thin flexible but very tough sheets, consisting of interlaced fibers; it is usually nearly white in color.

There is also, as with pyroxene, a variety which contains alumina, and is dark green or brown to black in color; this variety is called common *hornblende* (a name sometimes given to the whole species) and corresponds to augite under pyroxene. Manganese is also present in certain kinds of amphibole. Before the blowpipe amphibole behaves essentially like pyroxene.

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* A fibrous variety of serpentine is also called *asbestus*; it is easily distinguished, because it contains about fourteen per cent of water; it is described on a later page, and includes most of the asbestus mined for use in the arts.

Amphibole occurs in crystalline limestone (the variety tremolite); also associated with talc or serpentine (actinolite); in granitic rocks and in certain volcanic rocks (hornblende). It also forms rock-masses, as hornblende rock, hornblende schist, etc. At many localities it occurs associated with pyroxene.

CROCIDOLITE, also called *blue asbestus*, is related to amphibole. It occurs in fine fibrous forms of a delicate blue color. The fibers often penetrate quartz and then make a handsome ornamental stone, especially when by alteration they have become yellow (being changed to limonite). This is the well-known *tiger-eye* brought in large quantities from South Africa.

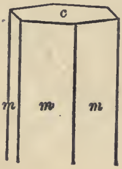
Beryl. Beryllium silicate, $Be_3Al_2Si_6O_{18}$.

BERYL is one of those species which are almost always in distinct crystals and usually in forms easy to recognize; it is also interesting because some varieties are used as a gem. The crystals are hexagonal prisms, sometimes quite slender, again stout, and occasionally very large; it is only rarely that they show any terminal planes (Figs. 281, 282, see also Figs. 69–71, p. 38).

The hardness of beryl is 7.5 or a little above that of quartz, and on this account and because of the beautiful color it sometimes has it ranks as one of the precious stones; the specific gravity is 2.7. The luster is vitreous or glassy,—in this respect also it resembles quartz,—and the color is usually some shade of green: bluish green in common beryl, clear mountain-green in the variety called *aquamarine,* and a deep emerald-green in the highly-prized variety, *emerald.* There are also light or dark yellow kinds sometimes having a rich golden color, and occasionally white and, still more rare, pink kinds.

The formula $Be_3Al_2Si_6O_{18}$ or $3BeO.Al_2O_3.6SiO_2$ gives the percentage composition: Silica (SiO_2) 67.0, alumina (Al_2O_3) 19.0, glucina (BeO) 14.0 = 100. The color of the emerald is usually attributed to a minute amount of chromium. It is infusible before the blowpipe and is not attacked by acids.

281.



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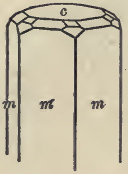


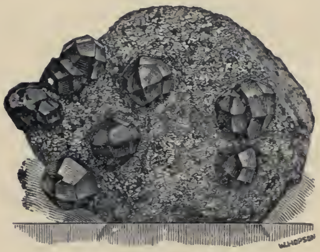
Beryl is found in granite rocks, with feldspar and quartz; the granite veins of New England and North Carolina often afford it in beautiful specimens. The beryls of Acworth, N. H., are sometimes as large as a barrel. The finest emeralds come from near Muso in Colombia, South America; others are found in the Ural, and some in North Carolina.

The element BERYLLIUM—also called Glucinum—which is prominent in the species beryl, is a rare one and is only known in a small number of other species, none of them common. Of these *chrysoberyl* ($BeO.Al_2O_3$, p. 242) and the silicate, *euclase,* are the most important; both of these are used as gems; there are also several other silicates, of which phenacite (Be_2SiO_4) occurring in glassy rhombohedral crystals is the most important; also two rare phosphates of beryllium (*herderite* and *beryllonite*).

Garnet.

GARNET is another species which, like beryl, is almost always in distinct crystals, and as these crystals are commonly isolated and scattered through the rock, it is not difficult to recognize them. There are, however, massive kinds needing some skill for their identification; these are occasionally used in the same way as emery, though much less hard.

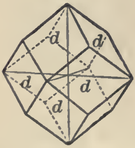
283.



Garnet crystals in mica schist.

The crystals are usually twelve-sided, having the form of a rhombic dodecahedron (Fig. 284), or twenty-four-sided and then called a trapezohedron (Fig. 285). There are also combinations of these two forms (Fig. 286), as also of the dodecahedron with the planes of a hexoctahedron (Fig. 287). It should be remembered that the dodecahedron has angles of 120° between two adjacent faces, while these

284.



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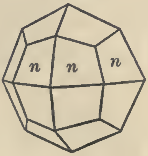

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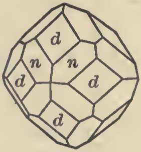

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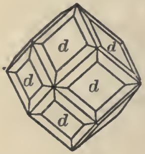


planes themselves are diamond in shape with plane angles of 60° and 120°. The trapezohedron (*n*) has quadrilateral faces, and the angles over the two kinds of edges are 131° 49′ and 146° 27′.

The hardness of garnet is 7 to 7.5, and the specific gravity varies from 3.2 to 4.3. The luster is vitreous, and the color, while most commonly red, varies also from the colorless kinds to those which are yellow, brown, black, and green.

The composition of the different kinds of garnet varies widely—as shown in the following list—and with this the color and specific gravity also change; the form, however, is the same for all kinds.

The chief kinds, or subspecies as they are in fact, with their formulas are given here; but between these there are also many intermediate varieties:

Grossularite,	Lime-alumina Garnet,	$3CaO.Al_2O_3.3SiO_2$.
Pyrope,	Magnesia-alumina Garnet,	$3MgO.Al_2O_3.3SiO_2$.
Almandite,	Iron-alumina Garnet,	$3FeO.Al_2O_3.3SiO_2$.
Spessartite,	Manganese-alumina Garnet,	$3MnO.Al_2O_2.3SiO_2$.
Andradite,	Lime-iron Garnet,	$3CaO.Fe_2O_3.3SiO_2$.
Uvarovite,	Lime-chromium Garnet,	$3CaO.Cr_2O_3.3SiO_2$.

The kind called *grossularite* is a silicate of lime and alumina; it may be colorless, white, pale yellow, or green, also brownish yellow or cinnamon-brown, and occasionally rose-red. The specific gravity is 3.55 to 3.66. The commonest kind is brownish red, and is called *cinnamon-stone* or hessonite. The original grossular garnet is green; it was named from the botanical name for the gooseberry.

Pyrope, or magnesia garnet, is a silicate of magnesia and alumina; it often has a deep red color, and when perfectly clear is used as a gem and called *precious garnet.* The specific gravity is 3.7 to 3.75.

Almandite, or almandine garnet, includes a large part of the common garnet, the rest belonging to andradite. It is a silicate of iron and alumina and is ordinarily red in color, but sometimes black. When clear so that it can be cut into gems it is, like pyrope, also called precious garnet. The specific gravity varies from 3.9 to 4.2, increasing with the amount of iron present.

Spessartite, or manganese garnet, is a rarer kind. It is a silicate of manganese and alumina and has a brownish-red or hyacinth-red color. The specific gravity is 4.0 to 4.3. One kind found in Virginia is used as a gem, it being perfectly transparent and of a peculiar shade of red.

Andradite, or the common iron garnet, is a silicate of lime and iron. It varies in color from pale yellow to apple-green or emerald-green, also to red, brown, and black. Much of the common garnet belongs here, and from this fact it is obvious that almandite and andradite can be surely separated and identified only by analysis. Specific gravity 3.8 to 3.9. Topazolite is a topaz-yellow variety; melanite is black; demantoid from Siberia, which is a beautiful green, is used as a gem.

Uvarovite, or chrome garnet, is a rare kind of a fine emerald-green color and distinguished in composition by its containing lime and chromium. Specific gravity 3.5.

The common kinds of garnet fuse easily and give a light brown or black glass; the latter is magnetic if much iron is present. The borax beads give reactions for iron in most cases, and often also for manganese.

Garnet commonly occurs in crystals scattered through granite, gneiss, or mica schist (almandite or andradite), also in crystalline limestone (grossularite); with serpentine (pyrope) or chromite (uvarovite); also in some volcanic rocks (melanite, rarely spessartite).

Related to garnet are the following rare species:

Helvite, a silicate of beryllium, manganese, and iron, also yielding sulphur; it crystallizes in tetrahedral forms, color commonly yellow.

Danalite, in octahedral crystals or masses of a flesh-red to gray color; composition near that of helvite, but contains also zinc.

Eulytite, a silicate of bismuth, occurring in yellow to gray tetrahedral crystals.

Zunyite, a tetrahedral fluo-silicate of aluminium.

THE MICAS.

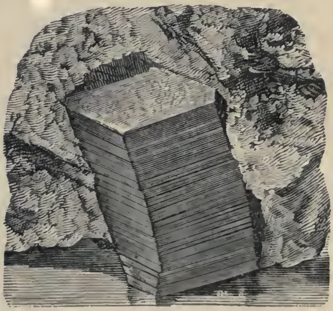
The Micas are characterized before all by their very perfect cleavage, in consequence of which they admit of being split into leaves much thinner than a sheet of paper —in fact it is difficult to set any limit to the extent to which this process may be carried. These leaves or sheets are usually very elastic and spring back with force when bent, but there are kinds of mica in which this elasticity is wanting and sometimes the leaves are brittle. The natural plates of mica have usually the form of either a rhomb with angles of 120° and 60°, or a hexagon, all the angles being 120°. The micas are silicates of alumina with potash, rarely soda or lithia, also magnesia, iron, and some other elements.

The most important species is *muscovite,* or potash mica; somewhat less so is *biotite,* the magnesia-iron mica, to which *phlogopite* is closely related, and *lepidolite* or lithia mica is a rather rare though interesting species.

Muscovite. Potash mica, $(H,K)AlSiO_4$.

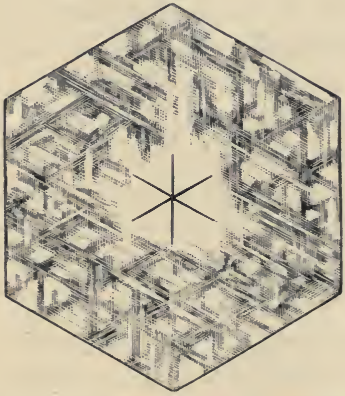
MUSCOVITE is the common mica which in the form of clear or slightly smoky-colored plates is used for the openings of stoves and lanterns and even for the windows of houses in some regions where glass is difficult to obtain; it was this last use in Russia that gave the name to the mineral of *Muscovy glass,* whence the mineralogical name of Muscovite.

288.



Muscovite commonly occurs in scales or sheets without any regular form, its crystallization having been constrained by the surrounding quartz or feldspar. In favorable cases, however, distinct crystals are found which on top may have the form of either a rhomb with angles of 60° and 120°, or one with the acute angles cut off (Fig. 288), or it may be a regular hexagon. The sides of the crystals usually taper sharply and are rough with the edges of the plates; this makes them look dark, but more light can pass through in this direction than in the other perpendicular to the perfect basal cleavage. The structure of the sheets, even when they have no regular shape, conforms to this hexagonal outline; this is shown by the fact that when a point not too sharp is held against a sheet and a blow struck with a hammer, a six-rayed star with branches intersecting at angles of 60° is the result (see the center of Fig. 289). These branches are parallel to the sides of a crystal having a hexagonal outline. The same thing is shown by the fact that the transparent magnetite (Fig. 289) which is sometimes found in muscovite forms a network along lines having the same direction.

289.



Besides the kinds which are in distinct crystals or in plates there are others made up of minute scales, sometimes aggregated into compact forms or those with a featherlike structure as in *plumose mica.* The plates or scales are sometimes arranged in spherical forms like balls, and these occasionally have also a radiated structure.

The cleavage has already been spoken of as perfect parallel to the top or basal plane. The hardness of mica on the cleavage surface is only 2 to 2.5, but the edges are somewhat harder; the specific gravity is 2.76 to 3. The luster is vitreous, but often silvery and pearly. The color depends upon the thickness of the sheet: it is dark brown when rather thick, and becomes lighter and finally colorless when in very thin sheets. Smoky brown is the common color. There are, however, yellow, pink, and green kinds, while the silvery kind was long ago called *cat's silver* and the yellower scales *cat's gold.* It is possible for a person not very experienced to mistake the minute yellow scales scattered through a rock for particles of gold, but a touch with a knife shows the difference.

Muscovite is a silicate of alumina and potash having essentially the formula $KAlSiO_4$ or $K_2O.Al_2O_3.2SiO_2$. A little water is usually yielded when a fragment is heated very hot, and this water is believed to be formed from the hydrogen in the compound which takes the place of part of the potassium. Some varieties, which give off water more easily, have a greasy feel, while the folia have little elasticity. It is difficult to fuse, and usually melts only on very thin edges. It is not decomposed by acids.

Muscovite is commonly found in scales or plates in granite, gneiss, and similar rocks. In what are called granite veins, where the ordinary constituents of granite, the feldspar, quartz, and mica are crystallized out in large masses, the mica is sometimes found in immense sheets a yard or more across, and may then be mined with success. These granite veins, as stated on p. 287, are very interesting to the mineralogist, for in them he looks not only for well-crystallized specimens of the three essential minerals named, but for many other rarer minerals, as often tourmaline, beryl, apatite, garnet, also columbite, samarskite, microlite, uranium compounds and others.

Some of the localities of these granite veins, or pegmatite veins as they are sometimes called, are at Paris and Hebron, Maine; Acworth, N. H.; Goshen and Chesterfield, Mass.; Haddam and Branchville, Conn. They also occur in Pennsylvania and the states south, especially western North Carolina, where the mica mines are famous mineral localities; further in Colorado, S. Dakota, Canada.

The use of mica for stove-windows and lanterns has been spoken of; this is an important industry, and the mica mines of North Carolina before alluded to produce considerable amounts. Mica is also brought from Greenland and from India. Besides this most important use of mica, the scales too small to be cut, and trimmings of larger sheets, are ground to powder and employed to give a silvery sheen to wallpaper.

PINITE is a mineral related to common potash-mica in composition, but compact in structure and derived from the decomposition of some one of a number of other minerals, as, for example, iolite, nephelite, scapolite, etc.

Biotite. Magnesia-iron Mica.

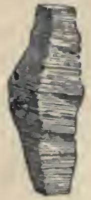
BIOTITE is the second most important kind of mica. It includes most of the dark green, brown, or black mica found in granite and other rocks, especially those of volcanic or igneous origin. It occurs usually in crystals with hexagonal outline and in irregular imbedded scales.

The hardness is about 2.5 to 3, like that of muscovite, but the specific gravity is sometimes a little higher, 2.7 to 3.1. The luster is bright and pearly on the cleavage surface, but vitreous on the edges. The color, as already stated, ranges between green or brown to black. There is a wide variation in color, however, corresponding to the variation in composition.

Some biotite—besides silica and alumina—contains magnesia and potash with but little iron, while other kinds contain much iron and almost no magnesia; the iron kinds have the darker color. A mica close to biotite and containing a large amount of iron is called *lepidomelane*, because found in black scales.

PHLOGOPITE is a mica near biotite and sometimes regarded as only a variety of it. It occurs in six-sided crystals, often rough tapering prisms (Fig. 290), and is found usually in limestone or in serpentine rocks, and often has a copper-red color on the cleavage surface. To phlogopite belongs the interesting star-mica of northern New York and Canada, a brown mica which shows a fine six-rayed star when a candle flame is viewed through it. This phenomenon is called *asterism*, and

290.



is explained by the presence of minute rodlike crystals (often of rutile) enclosed in the mica and lying in positions parallel to the six-rayed star obtained by a blow. Sometimes a twelve-rayed star is seen.

Lepidolite. Lithia Mica.

Lepidolite, or lithia mica, is another kind of mica, but not a common one. It is often found in masses seeming to have a close granular structure, but really made up of minute scales, and this has given it the name from the Greek (λεπίς, *a scale*). The scales, however, are sometimes large, and occasionally lepidolite is found in plates like other micas.

The color is commonly lilac or pink, and this kind of mica, the granular kind especially, is often found with prismatic crystals of lithia tourmaline imbedded in it, making specimens of great beauty. In consequence of the presence of lithia this mica yields a red flame when heated with the blowpipe. Specimens of this kind come from Maine, also from California; there is a foreign locality in Moravia.

The Vermiculites include a series of mica-like minerals, which separate by cleavage into soft pliable and inelastic leaves. The luster is pearly or bronzelike, and the color usually yellow or brown. They contain a considerable amount of water, and, on this account, when heated so that the water is driven off, the leaves open out, or exfoliate, into peculiar wormlike threads of the most curious appearance. The force of expansion is often sufficient to break a glass tube in which the fragment is being heated. This property has given the name from the Latin, *vermiculari*, to *breed worms*. The vermiculites have been derived from the alteration of some of the micas (as biotite or phlogopite), or the chlorites, so that the composition is often rather indefinite, and hence the mineralogist does not think very highly of them.

To the micas are related several rather rare species, of which the most important is MARGARITE, or pearl mica; others are chloritoid, ottrelite, etc. They are sometimes called *brittle micas*, because the folia are rather brittle. Margarite has a pearly luster on the cleavage surface and a grayish or pinkish color; it is a silicate of alumina and lime, and is often associated with corundum. *Ottrelite* usually occurs in small brown scales in a rock called "ottrelite-schist".

THE CHLORITES.

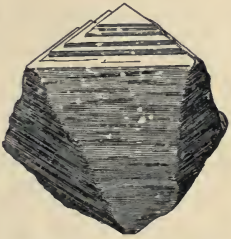
The CHLORITES are like the micas in many respects: thus in basal cleavage, in the occurrence in scales or plates, and in the hexagonal outline of these plates. They are easily distinguished, however, for the plates even when large show little or no elasticity, but when bent finally break. The name chlorite is from the Greek word for *green* (χλορός), the same word which has given the name to the yellow-green gas chlorine, but there is no other relation between the chlorites and chlorine. Besides the green chlorites there are others that are rose-red.

The chlorites are silicates of alumina, iron, and magnesia with water, the amounts of the different elements varying widely, and hence a number of species are included. The most prominent one is clinochlore, also sometimes called ripidolite, and the related penninite. Besides these crystallized chlorites there are also kinds in minute scales usually bright green in color, and others that are quite dense and compact. These kinds of chlorite are found in rocks and form the mass of chlorite rock and chlorite slate.

Clinochlore.

CLINOCHORE is the most distinctly characterized of the chlorites occurring in plates, sometimes large, having a fine green color and showing the characteristic basal cleavage. The plates have a hexagonal outline and the crystals sometimes appear as roughly hexagonal; they are truly monoclinic, however, and hence the name. Figure 291 is from a drawing of a large crystal of clinochlore (one third natural size) found at West Chester, Pennsylvania.

291.



The hardness of clinochlore is 2 to 2.5, and the specific gravity 2.65 to 2.78. Besides the bright green kinds there are others which are rose-red and white. It yields water in the closed tube and fuses with difficulty in the forceps; a reaction for iron with borax is ordinarily obtained. Clinochlore occurs most commonly in chloritic and talcose rocks or in serpentine.

PENNINITE is another kind of chlorite very like clinochlore, in fact not to be distinguished from it in composition, but only in the form of the crystals.

Chrysolite, or Olivine. $(Mg,Fe)_2SiO_4$.

CHRYSOLITE is a silicate of magnesia and iron having a vitreous luster and bright yellowish-green color. It is hard, H. = 6.5 to 7, and also of high specific gravity, G. = 3.3 to 3.6, the higher values belonging to the kinds with most iron. The luster is vitreous, and the color, besides that mentioned, may be yellow to olive-green and brown. The composition is $(Mg,Fe)_2SiO_4$ or $2(Mg,Fe)O,SiO_2$. As this method of writing the formula indicates, the relative amounts of magnesia and iron vary widely, from kinds with little iron (G. = 3.26) to those containing 30 p. c. (G. = 3.57).

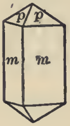
Chrysolite is not a common mineral, but it is an important one in connection with a number of eruptive rocks, especially basalt, in which it is often scattered in grains; it is also a common mineral in some meteorites. One celebrated specimen found in Siberia in 1749 consists of a spongy mass of metallic iron containing bright yellow grains of chrysolite. The clear yellow-green kinds of chrysolite, as those from the Orient, are sometimes used as a gem; one kind found in Arizona has been called Job's tears because of their peculiar pitted appearance.

Chrysolite (golden-stone, from χρυσός, *gold*, and λίθος, *stone*) is an old term in the mineralogy of former times, given to a number of yellow minerals used as gems, thus to beryl, topaz, chrysoberyl, zircon, etc.

Zircon. Zirconium silicate, $ZrSiO_4$.

ZIRCON is a rather rare mineral found in square prisms or pyramids, commonly quite small. In these the angle between the prism (m) and pyramid (p) is 132° 10′, and the angle between two adjacent pyramidal faces (p) is 123° 20′ (Figs. 292 to 294); the crystals are sometimes low pyramids, and again long prisms terminated by the pyramidal planes. Crystals which are more highly modified also occasionally occur; some of them are figured on p. 34, Figs. 56–58.

292.



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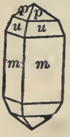

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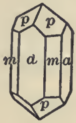


The hardness of zircon is 7.5, and the specific gravity is 4.7. The luster is brilliant adamantine, and the color varies from colorless through varies shades of reddish brown and yellow. Its high luster makes it when clear prized as a precious stone; in fact the gem called *hyacinth* is a variety of zircon having a reddish color. There is no very distinct cleavage, but the fracture is conchoidal.

Zircon consists of silica and zirconia, its formula being $ZrSiO_4$ or $ZrO_2.SiO_2$, which requires: Silica 32.8, zirconia 67.2 = 100. It is quite infusible and not attacked by acids.

Zircon is sometimes found in crystalline limestone, also in various crystalline rocks. In some regions it occurs in the rock so abundantly that when the rock has been worn down by the weather it is left unaltered in considerable quantities. It may then be obtained by washing the gravel after the manner of the gold-miner. Fine crystals are obtained in New York, and very large ones in Canada, as in Renfrew County; good specimens also come from North Carolina and Colorado; Norway and the Ural Mountains are famous foreign localities.

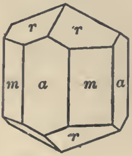
THORITE is related to zircon, having the same crystalline form, while in composition it is essentially a silicate of thoria ($ThSiO_4$); it is, however, much rarer. Usually it is found in altered and hence hydrated forms. *Orangite* is an orange-yellow variety. The use now made of the earth thoria is mentioned under the description of monazite (p. 271).

Scapolite.

SCAPOLITE is the name strictly of a group of minerals, all crystallizing in square prisms, and consisting of silica, alumina, lime, and soda, but varying rather widely in composition, somewhat as do the feldspars.

The common kind of scapolite is called WERNERITE, after an early German mineralogist. It is found in crystals having the form of a square prism, or an eight-sided prism formed of two square prisms (*a* and *m* in Fig. 295), parallel to each of which there is good cleavage. The pyramid *r* has an angle of 136° 15′, or on *m* of 121° 50′. Massive varieties are also common: they often show a faint fibrous structure on the surface. The hardness is 5 to 6; the specific gravity 2.7; the luster is vitreous or pearly, and the color commonly varies from white to gray; there are also yellowish, reddish, greenish and bluish varieties.

295.



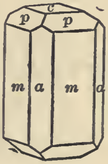
The composition of a typical specimen is as follows: Silica (SiO_2) 51.9, alumina (Al_2O_3) 26.5, lime (CaO) 12.9, soda (Na_2O) 7.2, chlorine (Cl) 2.0 = 100.5. Scapolite fuses easily before the blowpipe with intumescence to a white glass full of bubbles (hence called *blebby*). It is partially decomposed by hydrochloric acid. The form and cleavage are the most distinctive characters.

MEIONITE, DIPYRE, and MARIALITE are others of the scapolites.

Vesuvianite, or Idocrase.

VESUVIANITE takes its name from Vesuvius, because the igneous rocks of that famous volcano have long furnished some of the finest specimens. It occurs in tetragonal crystals of varied habit, sometimes highly complex; a simple form is shown in Fig. 296. Here the angle of the pyramid *p* is 129° 20′, while that of *c* on *p* is 142° 45′. There are also massive forms, either columnar or granular.

296.



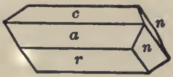
The hardness is 6.5, and the specific gravity 3.4. The luster is vitreous, inclining to resinous, and the color, commonly brown to green, may be also sulphur-yellow and bright blue; transparent crystals occur, but are not the rule.

The composition is complex, it being essentially a silicate of alumina, iron, and lime. Before the blowpipe it fuses with intumescence at 3. It is only partly decomposed by hydrochloric acid. It is found most commonly in granular limestone; also in serpentine, chorite schist, and related rocks. Commonly associated minerals are grossularite (garnet), diopside (pyroxene), also epidote, titanite, etc. It resembles some brown garnet and tourmaline (also epidote), but is more fusible, and when crystallized has a different form.

Epidote.

EPIDOTE is found usually in prismatic crystals, often very slender and terminated at one end only; they belong to the monoclinic system. Fig. 297 shows a common type, in which the angle *ca* = 115° 23′, *ar* = 128° 19′, *nn* (at the end) = 109° 31′. The same form is represented in Fig. 298 in an erect position; the former, however, is that which shows the monoclinic character. It also often occurs in fibrous or columnar kinds and others that are compact and granular. The crystals show perfect cleavage parallel to the face *c* and imperfect cleavage parallel to *a*.

297.



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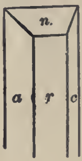


The hardness is 6 to 7, and the specific gravity 3.3 to 3.5. The luster is vitreous, and the color commonly green, although there are black and pink varieties; the peculiar yellow-green or pistache-green of ordinary epidote is so characteristic that in the majority of cases it suffices to distinguish it from some kinds of amphibole and from tourmaline, both of which minerals it resembles.

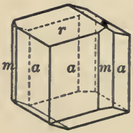
Epidote is a silicate of alumina, iron, and lime, but it varies rather widely in composition, especially as regards the relative amounts of alumina and iron. It fuses with intumescence rather easily, because of the iron it contains, and gives a magnetic globule. It is partially decomposed by hydrochloric acid. It is a common mineral in many crystalline rocks, as gneiss, mica-schist, amphibole-schist, etc. Beautiful specimens come from the Alps; in the United States from Haddam, Conn., and other localities.

Closely related to epidote is the rare ALLANITE, a black mineral containing cerium and other rare elements; also ZOISITE, a white to ash-gray, greenish, or pale red mineral often in columnar or compact masses. It is like epidote in composition, except that it contains almost no iron. Before the blowpipe it swells up and fuses to a blebby glass; after ignition it gelatinizes with hydrochloric acid.

Tourmaline.

TOURMALINE is one of the most attractive minerals among the silicates; its varieties show a greater range of color than any other species, not even excepting fluorite, and some of the clear pink and green kinds make beautiful gems.

299.



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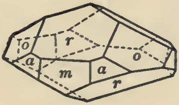

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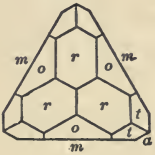
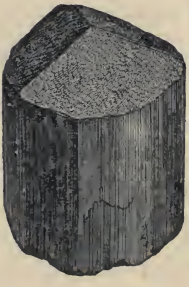


It is almost always found in prismatic crystals, bounded often by three sides, sometimes by six, also by nine, and not infrequently rounded so that there are no distinct faces to be distinguished at all. These prisms give, when broken across, as they are often observed in the enclosing quartz or other rock, outlines which are usually three-sided (Fig. 301), also six-sided or nine-sided. It belongs to the rhombohedral system, and the terminal faces are consequently arranged in three or multiples of three. The commonest form is the obtuse rhombohedron (Figs. 299, 302), which gives a terminal angle of about 133°. There are also many more complex forms, and not infrequently when both ends of a crystal are finished by planes (Fig. 300), we find them unlike. Corresponding to this dissimilar molecular structure, in the opposite directions of the vertical axis, is the development of + and − electricity at these ends on change of temperature (see pyro-electricity, p. 97). The prismatic faces are usually lined or striated in a vertical direction, and sometimes to such an extent that the whole crystal is rounded (Fig. 302). Radiating groups of crystals (Fig. 303) are common. Massive kinds commonly show a columnar structure, the mass appearing as if made up of a bundle of parallel crystals; there are also varieties which are simply compact. No distinct cleavage is noted,

302.



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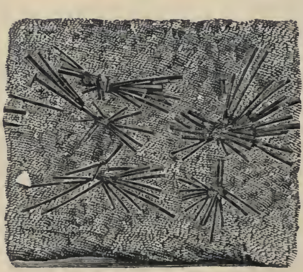


but the fracture varies from uneven to imperfectly conchoidal. It is brittle, and the effect of the fractured black mass is often like a piece of coal.

The hardness of tourmaline is 7 to 7.5, and the specific gravity varies from 3 to 3.2. The luster is vitreous, and the color, as remarked above, very varied. Black is the commonest kind, and this the form of tourmaline that is found so often in granite. There are also kinds of tourmaline that are yellow and brown; others that are blue, green, pink, and gray; while occasionally the crystals are white or colorless. It is not uncommon to find crystals in which the color differs in different parts: they may be pink at one end and green at the other, or there may be a pink center surrounded by a green border, and so on.

Tourmaline is a silicate of alumina containing iron, magnesia, and the rare element boron, also lithia, soda, and potash in some kinds. There are a number of distinct varieties differing in color and in composition. Common black tourmaline is an iron kind; the brown tourmaline is a magnesian, while the beautiful pink variety contains lithia. This last kind, called *rubellite,* is often associated with the lithia mica, lepidolite, as has been remarked before.

The brown magnesian varieties fuse rather easily to a blebby enamel, while the iron kinds fuse with difficulty, and the lithia variety is infusible. If first powdered and then carefully mixed with three times its volume of potassium bisulphate and its own volume of fluorite (all in powder), and if then the mixture is supported on a platinum wire in the blowpipe flame, it colors it momentarily *green* because of the boron liberated. This is a delicate and important test (for tourmaline is not infrequently a difficult mineral to recognize), and the student should practice it on a known specimen until he is always successful.

Tourmaline is especially common in granite and similar rocks, but it also occurs in crystalline limestone; it is found in fine specimens at many localities in New England, New York, New Jersey, Pennsylvania, also the states to the south; noted foreign localities too are very numerous, as Elba, Brazil, etc. The black needles, prisms or clusters of prisms, sometimes in radiating groups, are very characteristic; they are hard but show no cleavage and have a peculiar fracture like that of coal. It is distinguished by these characters from similar varieties of amphibole and epidote, which it often resembles. The boron test above described is conclusive when the identification is otherwise doubtful.

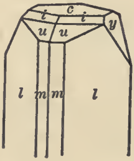
Topaz. Aluminium fluo-silicate.

TOPAZ is another gem silicate, beautiful in its fine crystals and in its brilliancy of luster and color. It occurs in prismatic crystals, terminated by rhombic pyramids, sometimes acute, sometimes obtuse. The angle of the common prism (m) is 124° 17′, but another prism (l) of nearly 90° (86° 49′) is also common; the angle $uu = 141^\circ\ 0'$ and $oo = 130^\circ\ 23'$ (both in front). There are also coarse crystals and massive or fibrous forms, but these last are not so common. The perfect basal cleavage of topaz is one of its most characteristic points. Hard as it is, it is easily broken in a direction across the prism, and will yield thin plates with very smooth faces.

The hardness of topaz is 8, and the specific gravity about 3.56. The luster is vitreous, and the color varies from colorless to white, wine-yellow, and blue. Pink topaz is sometimes found, but most of the pink is obtained by heating the deep wine-yellow crystals from Brazil.

Topaz is a silicate of alumina containing some 17 per cent of the rare element fluorine; the formula is Al_2SiO_5, like andalusite, with, however, part of the oxygen replaced by fluorine. It is infusible before the blowpipe, but gives a fine blue when ignited after being moistened with cobalt solution; it also gives the reaction for fluorine (p. 153) when fused in the closed tube with salt of phosphorus.

304.



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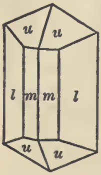

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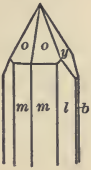


Topaz is commonly found in gneiss or granite with tourmaline, mica, beryl; also cassiterite or tin-stone, apatite, fluorite. Siberia and Brazil yield beautiful specimens, also the tin-mining regions of Saxony, Bohemia, and Cornwall. A notable locality in this country, especially for very large crystals, is at Stoneham, Maine; another at Trumbull, Conn. It sometimes occurs in fine clear crystals in volcanic rocks, as in Colorado, Utah, and Mexico.

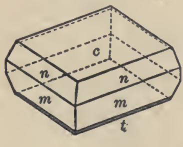
Danburite is a silicate of calcium and boron with the formula $CaB_2(SiO_4)_2$ or $CaO.B_2O_3.2SiO_2$ occurring in pale yellow prismatic crystals, closely resembling topaz in habit and angles; also in imbedded crystalline grains. The hardness is 7 to 7.5; specific gravity 3.0; luster vitreous to greasy. It fuses in the forceps (at 3.5) and gives a green flame (boron).

IOLITE, or Cordierite, is a silicate of alumina, iron, and magnesia. It is sometimes found in prismatic crystals, also in massive forms commonly showing a fine blue color. Hardness 7 to 7.5; specific gravity 2.6. Much iolite is altered to pinite (p. 307).

Titanite, or Sphene. $CaTiSiO_5$.

TITANITE is a silicate of calcium containing titanium. It is almost always in crystals, which vary much in form, though often showing a form with an acute edge, which has given to it one of its common names, *sphene* (from the Greek *σφήν*, *wedge*). The crystals are monoclinic in form and of very varied habit; a common kind is shown in Fig. 307; angles $mm = 113° 31'$, $nn = 136° 11'$, $mn = 152° 46'$. $cn = 141° 44'$. Massive lamellar or compact kinds are less common than the distinct crystals.

307.



The hardness is 5 to 5.5, and the specific gravity 3.54. The luster is resinous to adamantine, and the common color varies from yellow to brown and black; there are also green and pink kinds.

The formula is $CaTiSiO_5$ or CaO,TiO_2,SiO_2, and the percentage composition: Silica (SiO_2) 30.6, titanium dioxide (TiO_2) 40.8, lime (CaO) 28.6 = 100. Iron is present in the darker-colored kinds, and sometimes also manganese. It fuses with intumescence to a yellow, brown, or black glass. With salt of phosphorus it gives a violet bead in the reducing flame (titanium), which is distinct unless the mineral contains a good deal of iron.

Titanite is not a common mineral, but it is found in fine crystals, as in limestone with apatite, in northern New York; also in very large crystals in Renfrew County, Ontario, Canada. The Alps yield beautiful crystals.

Andalusite. Aluminium silicate, Al_2SiO_5.

ANDALUSITE is a silicate of alumina, named from the first locality where it was identified, Andalusia in Spain. It is found in rhombic prisms having an angle of about 90°. The crystals are usually imbedded and seldom distinctly formed; sometimes they are hardly distinct at all until the weather has removed the surrounding rock and left the harder, more resisting crystals protruding from the surface as ribs or veins. Coarse prismatic to columnar and massive forms are common.

An interesting variety of andalusite is that called *chiastolite* or *macle.* In this there are parts of the crystal that are white and others that contain carbonaceous impurities, and are hence black; often these are regularly arranged through the length of the crystal, giving a variety of forms on the cross-section, as shown in Fig. 114, p. 55. As seen there the form on the cross-section is a little like the Greek letter χ, and this resemblance has given it the name chiastolite.

The hardness is 7.5, and the specific gravity 3.2. The luster is vitreous, and the color varies from white or gray to pink, brown, or green.

The chemical formula is Al_2SiO_5 or $Al_2O_3.SiO_2$, and the percentage composition is: Silica 36.8, alumina 63.2 = 100. It is infusible before the blowpipe, and a fragment becomes blue when moistened with cobalt solution and ignited. Andalusite is not uncommon in crystalline or partly crystalline schists, as those of New England; sillimanite is a frequent associate. In the White Mountain region in New Hampshire, as on Mount Washington, andalusite is conspicuous in rough crystalline forms.

Cyanite and Sillimanite are two other minerals having the same composition as andalusite.

CYANITE, named from the Greek for blue (*κυανός*), because of its characteristic color, is usually found in thin-bladed crystals, showing a fine blue sometimes over the whole, sometimes as a central strip between paler or even colorless sides. There are also gray and green varieties and those which are columnar to fibrous. The hardness is only 5 on the flat side of the blades, but on the edges a little over 7; specific gravity 3.6; luster vitreous to pearly. Fine specimens come from North Carolina.

SILLIMANITE occurs rarely in prismatic crystals; usually it is in fibrous or columnar forms, and then the crystals are not distinct. There is a very perfect cleavage in a direction parallel to the length of the prisms. The hardness is 6 to 7, and the specific gravity 3.2; luster vitreous or subadamantine; color pale brown to gray and green. It is found in crystalline schists, often with staurolite.

PYROPHYLLITE is a silicate of aluminium containing water ($H_2O.Al_2O_3.4SiO_2$). It often occurs in foliated masses with radiated lamellar structure; also granular to compact (pencil-stone). Hardness 1 to 2; specific gravity 2.8 to 2.9; luster pearly; color white to green or yellow. In the forceps all but the compact varieties exfoliate, but fuse only on the edges with difficulty and give a blue (alumina) with cobalt solution.

AXINITE is a rather rare silicate of aluminium, calcium, iron and manganese, containing also boron. It occurs in triclinic crystals, often with a sharp edge (hence named from *ἄξίνη, an ax*); one form is figured on page 46, Fig. 98. Hardness 6.5 to 7; specific gravity 3.27; luster vitreous; color clove-brown to yellow and gray, also blue. It fuses easily and gives a green flame in the forceps, due to the boron.

Staurolite.

STAUROLITE, or Cross-stone,* is remarkable for the variety of its compound or twin crystals. The simple form is a rhombic prism with the angles of 129° 20′ and 50° 40′, and with these a dome, *d*, often occurs, making an angle of 124° 44′ with the top plane. This is not rare, but it is more common to find two crystals crossing each other, sometimes at right angles (Fig. 308, also Fig. 119, p. 58), sometimes at an angle of nearly 60°, as shown in Fig. 309; more complex twins, of the same interpenetration type, also occur where three or even four crystals are grouped together.

The hardness is 7 to 7.5, and the specific gravity about

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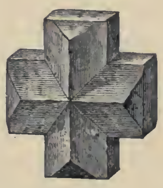
* The name is derived from the Greek words *σταυρός, a cross*, and *λίθος, a stone*.

3.7; the fracture is subconchoidal, and cleavage parallel to the side plane is sometimes noted. The luster is vitreous, and the color reddish, yellowish brown, brownish black, or gray.

Staurolite is a silicate of aluminium, iron, and magnesium, but its formula is quite complex. It occurs especially with garnet, tourmaline, cyanite, or sillimanite, in mica schist and gneiss; many localities are known in New England, very perfect crystals are found in Fannin County, Georgia, and in North Carolina.

308.



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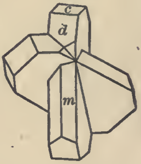


CHONDRODITE is a silicate of magnesium and iron containing fluorine. It occurs in yellow grains imbedded in crystalline limestone, also in deep red crystals associated, for example, with magnetite, as at Brewster, N. Y. Hardness 6 to 6.5; specific gravity 3.1 to 3.2. The mineral HUMITE, occurring in honey-yellow crystals at Vesuvius (Mt. Somma), is closely related to chondrodite.

Talc. Magnesium silicate, $H_2Mg_3Si_4O_{12}$.

TALC is remarkable among minerals because of its softness; on this account it is placed at the beginning of the scale of hardness. It is easily scratched by the nail and has a soapy, unctuous feel. The common form of talc is that in plates or leaves, foliated it is called, which separate easily because of the perfect cleavage; these leaves are not elastic like those of mica, but flexible.

There are also kinds of talc which are compact and show but little of the foliated character; this is especially true of the kind called *steatite* or soapstone, which is sawed into slabs and used for hearths and furnaces, also, when pulverized, as a lubricator. The Chinese make images and other small articles out of a fine-grained compact kind, and a similar kind is used for slate-pencils. Another variety, derived, however, from the alteration of a different mineral (Enstatite, p. 295), is fibrous, a little like asbestus, and is used, when ground up, for giving a silky gloss to wall-paper and to mix with wood-pulp in making paper; it is obtained from Edwards, N. Y.

The hardness of talc is 1, as stated above, and its specific gravity is 2.8. The luster is pearly, especially in the foliated kinds, and the color in the finest of these a beautiful sea-green; there are also white foliated kinds, and the massive varieties may be dark gray.

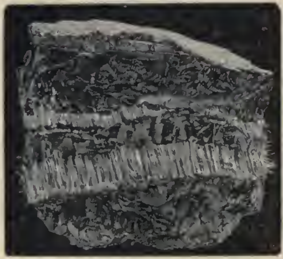
Talc is a silicate of magnesium, with the formula $H_2O.3MgO.4SiO$. The percentage composition is: Silica (SiO_2) 63.5, magnesia (MgO) 31.7, water (H_2O) 4.8 = 100. Upon being heated quite hot in a closed tube it gives off a small amount of water. It is a common mineral, often associated with serpentine and chlorite rocks; many localities are known in the eastern United States and Canada.

Serpentine. Magnesium silicate, $H_4Mg_3Si_2O_9$.

SERPENTINE is a remarkable mineral because of the variety of massive forms it assumes, although it is not known to occur in crystals of its own. The crystals of serpentine which are found are what are called pseudomorphs (p. 55), having been derived from some other species by chemical change. Thus the magnesium-iron silicate chrysolite—a mineral found especially in basaltic rocks—is often changed to serpentine, and then the serpentine is said to be a pseudomorph after the chrysolite, since it retains its form.

The translucent masses of serpentine of a deep oil-green color are called *precious serpentine.* A clouded or mottled variety, either green or red, is called serpentine marble or *verd-antique marble* or ophiolite; this last name, like that of the species, refers to the serpent-like markings so commonly observed. This kind is used as a building stone in Philadelphia and Baltimore. Other kinds of serpentine are foliated or lamellar and separable into brittle leaves. The most peculiar variety is the fine fibrous kind called *chrysotile* (not to be confounded with chrysolite). This usually occurs as thin seams in the massive mineral (Fig. 310). Chrysotile may be separated into fibers, very flexible and as soft as the finest silk. This variety is popularly called *asbestus,* but it must be remembered that there is another kind of asbestus of rather similar appearance which is a variety of the mineral amphibole (p. 297). The serpentine asbestus is extensively mined in the prov-

310.



ince of Quebec, as at Thetford, where it occurs in seams sometimes 3 or 4 inches in thickness. It is ground up and used (since it is a non-conductor of heat) for packing steam-pipes, etc.; also as asbestus roofing; as a lubricator; and so on.

The hardness of serpentine is usually from 2.5 to 3; it is hence easily scratched and often has a smooth feel, sometimes almost greasy; some varieties are harder than 3, up to 4 or even 5.5. The specific gravity is about 2.50. The luster is usually feeble and greasy or waxlike; the color, as stated, some shade of green to gray or nearly white.

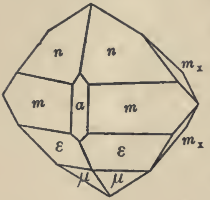
The composition of serpentine is given by the formula $3MgO.2SiO_2.2H_2O$, which requires: Silica (SiO_2) 44.1, magnesia (MgO) 43.0, water (H_2O) $12.9 = 100$; iron is often present in small amount. Heated in the closed tube it yields considerable water, but it fuses in the forceps only on the edges.

Besides the two minerals talc and serpentine there is also another important magnesium silicate, the mineral SEPIOLITE, better known as *meerschaum* (from the German). This is a soft white mineral, so light, because of its loose texture, as to nearly float on water when quite dry, and this is what gives it its familiar name, which means sea-foam. It is much used for the bowls of tobacco-pipes, and for this purpose is mined in Asia Minor.

Datolite.

DATOLITE is found in clear glassy crystals having usually a faint green tinge. The crystals are monoclinic in crystallization, and are complex and difficult to decipher even for one who has had a good deal of experience (Fig. 311, also Fig. 97, p. 45). It is noticed at once, however, on examining the surface spangled with crystals that there is little apparent uniformity in the shape of the faces, which is in agreement with their monoclinic character.

311.



There is also a kind of datolite occurring in forms resembling a pinkish porcelain, but it is only known from the Lake Superior copper-mining region; also another kind in botryoidal masses; but both of these are rare.

The hardness is 5 to 5.5, and the specific gravity about 3. The luster is vitreous, and the color white to greenish or pale reddish.

Datolite is a silicate of boron and calcium. It yields a little water when heated in the closed tube, and gives a green flame in the forceps (boron), at the same time fusing easily.

It occurs chiefly in the kind of eruptive rock found in New Jersey, Connecticut, and Massachusetts, and is often associated with the various minerals belonging to the Zeolite family. Like them it is a secondary mineral, that is, formed after the rock which encloses it, and usually out of the chemical material the rock affords by partial decomposition.

Prehnite.

Prehnite is another mineral occurring like datolite under the same conditions as the zeolites and associated with them. It is seldom in distinct crystals, usually in crystalline masses with a botryoidal or mammillary surface (Fig. 138, p. 68), or in groups of tabular crystals showing a series of little ridges in parallel position.

The hardness is 6 to 6.5, and the specific gravity about 2.9. The luster is vitreous, and the common color green, but it is sometimes white or gray.

Prehnite is a silicate of alumina and lime yielding a little water when heated in the closed tube. It fuses in the forceps rather easily, and is slowly decomposed by hydrochloric acid.

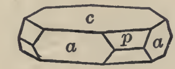
Apophyllite.

Apophyllite stands still closer to the Zeolites than either of the two preceding minerals; it is not only related to them in the way it occurs and in association, but also in its chemical composition—in fact it is sometimes called a zeolite.

It occurs in square prismatic or pyramidal crystals, but of a considerable variety in habit. The crystals may be simple square prisms terminated by the basal plane with its characteristic pearly luster, and then often looking like a cube, or the form may resemble a cube whose angles have been replaced, like Fig. 313 (compare Fig. 107, p. 50). Here it is to be noted that the angle made by the pyramid (*p*) on *c* (119° 28′) is not the same as that on the prism *a* (128°); further, it is noticed on close examination that the faces, *a*, have a vitreous luster and are often striated vertically, while the base, *c*, has a pearly luster and is often dull. Another form of crystal is sharply terminated by the pyramid *p*, and still another is in flat tables (Fig. 312).

The cleavage is perfect parallel to the top or base of the crystals (*c*), and hence the peculiar pearly luster noticed in this direction; elsewhere the luster is vitreous. The pearly luster is so peculiar that an old name of the mineral (ichthyophthalmite) means *fish-eye stone;* the name apophyllite refers to the character of exfoliating before the blowpipe. The hardness is 4.5 to 5, and the specific gravity 2.3 to 2.4. The crystals may be entirely colorless, or they may be white or rarely of a beautiful rose-pink.

312.



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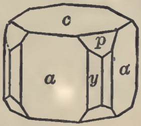

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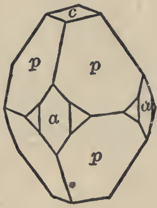
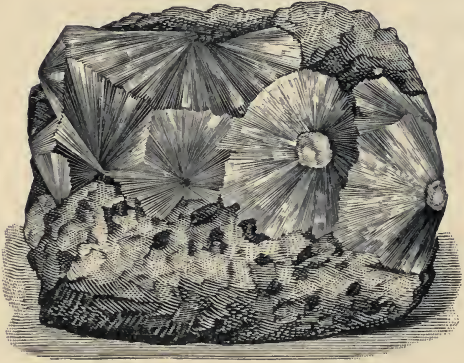


Apophyllite is a silicate containing lime and potash with a good deal of water and a small amount of fluorine. Before the blowpipe it exfoliates, whitens, and yields acid water, fusing to a vesicular enamel and coloring the flame a violet (potash). Beautiful specimens have been obtained from Bergen Hill, New Jersey.

Pectolite.

Pectolite is often found with prehnite, datolite, and various of the zeolites. The common form is massive and radiated or stellate, or in similar forms made up of acicular crystals (Fig. 315). Distinct crystals are rare; these are monoclinic and show two perfect cleavages. The hardness is 5, specific gravity 2.68 to 2.78; luster silky to subvitreous; color white or grayish.

315.



Pectolite is a silicate of lime and soda having the formula $HNaCa_2(SiO_3)_3$ or $H_2O.Na_2O.4CaO.6SiO_2$, which requires: Silica (SiO_2) 54.2, lime (CaO) 33.8, soda (Na_2O) 9.3, water (H_2O) 2.7 = 100. It yields water in the closed tube and fuses easily (at 2) to a white enamel. It is decomposed by hydrochloric acid with separation of silica.

THE ZEOLITES.

The Zeolite Family includes a number of beautiful minerals having a close relation to each other in manner of occurrence and in their chemical composition. They are all hydrous silicates, that is, they contain water, which is given off when a fragment is heated in a closed tube, and, like other hydrous silicates, they are of inferior hardness, chiefly 3.5 to 5.5, and low specific gravity, chiefly 2.0 to 2.4. They are readily decomposed by hydrochloric acid, some of them forming a jelly. Many of them bubble up, or intumesce when heated before the blowpipe, and this has given the name to the family from the Greek (ζεῖν) to boil.

The Zeolites are all said to be secondary minerals, which means that they were made subsequent to the time of formation of the rock in which they occur, unlike the feldspar, quartz, etc., which are part of the rock. They have been formed in most cases out of the materials of the feldspar or related minerals in the rock itself, and hence occur rather in crevices, seams, or in cavities, instead of in the solid mass.

They are all silicates of alumina, and with this lime or soda or potash; they do not contain iron or magnesia; hence they are like the feldspar and, indeed, are often called *hydrous feldspars.*

The zeolites, and also the minerals datolite, prehnite, apophyllite, pectolite (also calcite), which occur with them, are found frequently in connection with the dark-colored "trap rock," such as that which forms the Palisades of the Hudson, and is found also at various points in Connecticut and Massachusetts, also in Nova Scotia. Famous localities have been developed where railroad cuts or tunnels have been cut through ridges of this and similar igneous rocks (basalt, etc.), as at Bergen Hill, New Jersey, also similarly in British India. Beautiful specimens come from Nova Scotia. The zeolites are also found, but not so commonly, in granitic rocks.

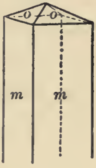
Thomsonite.

THOMSONITE is usually found in columnar masses with radiated structure, also in radiated spherical concretions, as in the beautiful water-worn pebbles found on the shores of Lake Superior at Grand Marais. Crystals are rare. The hardness is 5 to 5.5; specific gravity 2.3 to 2.4; luster vitreous or slightly pearly; color snow-white, pale red or green. It is a silicate of alumina, lime, and soda. Before the blowpipe it fuses easily (2) with intumescence to a white enamel; with hydrochloric acid it gelatinizes.

Natrolite.

NATROLITE is sometimes called the *needle zeolite* because it is so common to find it in very fine acicular, or needle-like, crystals. These crystals are often arranged in radiating tufts; sometimes they line oval cavities in the enclosing rock. When the crystals are larger, they are seen to have the form of a nearly square prism (angles 91° 15′) with a low pyramid on the summit (Fig. 316). There are also massive varieties having a fibrous or fine-columnar radiated structure.

316.



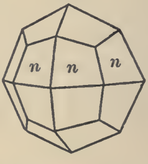
The hardness is 5 to 5.5; specific gravity 2.2 to 2.25; luster vitreous, sometimes a little pearly; colorless or white, also gray, yellowish, and reddish. It is a silicate of alumina and soda (natron), as its name indicates. Before the blowpipe it fuses quietly at 2 to a colorless glass; with hydrochloric acid it gelatinizes.

Scolecite is a rarer zeolite resembling natrolite in its massive forms, but it contains lime instead of soda. It takes its name from its behavior before the blowpipe, curling up as a worm before fusion.

Analcite.

Analcite is found in crystals having usually the form of a trapezohedron, shown in Fig. 317, resembling one of the common forms of garnet. It also less frequently occurs in cubes with three faces on each solid angle, like Fig. 16, page 24. The hardness is 5 to 5.5; specific gravity 2.22 to 2.3; luster vitreous; colorless, white, or pale yellow or gray. It fuses before the blowpipe at 2.5 to a colorless glass and gelatinizes with hydrochloric acid.

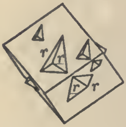
317.



Chabazite.

Chabazite is found in rhombohedrons, but, as the angle between two faces (95°) is not far from 90°, their aspect is often that of cubes, and it is possible for one not experienced to make a mistake. The crystals often interpenetrate each other (Fig. 318) in twining position a little like the cubes of fluorite.

318.



The hardness is 4 to 5; specific gravity 2.08 to 2.16. Luster vitreous; color white, yellow, also flesh-red. In composition it is a silicate of alumina and lime with small amounts of soda and potash. Before the blowpipe it intumesces and fuses to a blebby, nearly opaque glass; it is decomposed by hydrochloric acid with the separation of slimy silica.

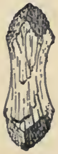
Acadialite is a reddish variety of chabazite from Nova Scotia; *phæolite* a colorless kind from Bohemia; and *haydenite* a yellowish kind from Jones Falls near Baltimore.

Gmelinite is another rhombohedral zeolite closely related to chabazite, but much rarer.

Stilbite.

Stilbite is named from one of its most important characters, its beautiful pearly luster on the side cleavage face. It is usually found in bundles of crystals, often looking like a sheaf of wheat tied tightly about the centre (Fig. 319); this has given it another of its names, *desmine,* from the Greek (δεσμός) for bundle. There are also radiated forms, seen, for example, on a flat surface of rock, but distinct crystals are rare. The cleavage is very perfect on the side face.

319.



The hardness is 3.5 to 4, and the specific gravity 2.1 to 2.2. The luster, as already stated, is brilliant pearly on the cleavage surface, the side face of the bundles which have been described. The color varies from white to yellow, and also to red or brown.

Stilbite is a silicate of alumina and lime. Before the blowpipe it exfoliates, swells up, and fuses (2 to 2.5) to a white enamel.

Harmotome is a rather rare zeolite, remarkable for containing 20 per cent of baryta. It is usually found in white to yellow or brown crystals of complex twinned structure. PHILLIPSITE is a related species, not, however, containing baryta; the crystals are similar to those of harmotome, but the color does not often vary from white.

Heulandite.

HEULANDITE, named after the owner of the famous Heuland cabinet, is found in fine monoclinic crystals with perfect cleavage parallel to the side plane, on which it has also a marked pearly luster that is very characteristic. It is like stilbite in this respect, but very different in form. The hardness is 3.5 to 4, and the specific gravity 2.2. The color is usually white, often milk-white, but red, gray, or brown varieties also occur. It resembles gypsum a little, but is much harder.

LAUMONTITE is a lime zeolite containing a large amount of water, part of which it is apt to lose on exposure to a dry air, whence it frequently falls to pieces in the cabinet. The common color is white (also red); the form monoclinic.

CHAPTER VIII.

ON THE DETERMINATION OF MINERALS.

It will seem to the beginner a difficult thing to become so familiar with the many different mineral species as to be able to recognize each of them at sight; and it *is* difficult, in fact impossible, even for the trained mineralogist to be always prompt and sure in his determination. For there are a large number of distinct species, between 800 and 1000, many of them very rare, while not a few appear in a great variety of forms. In the latter case the varieties sometimes depend upon fundamental differences of chemical composition, as among the garnets; and sometimes upon less essential distinctions of structure, color, and so on, as with the varieties of quartz, calcite, and fluorite. Hence it is obvious that the characters that can be perceived at once, without the aid of careful tests, are often insufficient to fix a mineral positively. The experienced mineralogist, while he learns to know minerals so well that he can name most of them at sight and seldom blunders, is ever distrustful of himself and often hesitates to give the name quartz to a specimen having to the eye the external characters of this common species without, for example, a confirmatory test of hardness. Confidence and hasty judgment belong to those who have little experience and a scanty knowledge of the difficulties of the subject.

But, on the other hand, to recognize most of the minerals, which are likely to be collected on a mineralogical excursion or to be obtained by exchange with other collectors, is generally easy even for the beginner, if he goes at the subject in the right way. For the number of *common* species is small, and quartz, feldspar, mica, calcite, and barite, also galena, sphalerite, pyrite, chalcopyrite, among metallic species, are constantly presenting themselves, and though their characters vary somewhat widely in different specimens, these are usually distinct, and almost always a simple test will make the matter sure.

First of all, then, the mineralogist should know these and other common species *well*, for the chances are many times greater that an unknown specimen is one of them than that it is a rare and little-known species. It may be rare, even a new one not before described and not given in any of the books; but this is a chance that does not often happen. A real difficulty, that even much experience does not entirely remove, lies in the fact that at any large mineral locality there are likely to be many nondescript specimens which show few distinct characters. Sometimes these are mixtures of several species, and often they arise from chemical decomposition of well-known minerals. About such specimens it may perhaps be impossible to say anything definite; in fact, exhaustive microscopic and chemical work is often needed to settle their character. In such cases the beginner may well turn to some one more experienced for counsel.

The best way, then, for one with a specimen of an unknown mineral in hand is to think of the common species first, and afterward of others which may suggest themselves, running over in mind or by reference to the book the characters observed and those of the species to which it is provisionally referred, but with care not to decide too hastily, but to give each character full weight. Do not give the name *albite* to a specimen of *barite*, either the tabular glassy crystals or the white massive granular kind, because both species are often white and also resemble each other in form, and overlook the fact that it is much too heavy as well as too soft. Do not give the name *beryl* to a crystal of *apatite* because it is a green hexagonal prism, and overlook the fact that it is quite too hard. Finally, do not hesitate to confess ignorance—that the experienced mineralogist is ever ready to do, and it is this fact that enables him from time to time to identify some rare and interesting species and perhaps occasionally one new to science.

As the student goes on to learn minerals better and better, the knowledge of the commoner species becomes so impressed upon his mind that he seldom hesitates, when a specimen of one of them is put in his hands, but its name suggests itself at once, and this without the careful summary and comparison of characters which the beginner must go through. Then a confirmatory test clinches the matter. But this power only comes with long experience, and even then it is sometimes necessary to carry on an exhaustive examination before a result is reached.

In the systematic determination of an unknown specimen the first thing to do, as was insisted upon in Chapter II, is to learn all that is possible about it by looking at and handling it. It has already been shown that in this way its form and structure may be at least partially determined; also its cleavage, if it shows any; and finally its luster, color, degree of transparency, etc. But at the same time the other senses must be kept on the alert, so that, for example, if the specimen is particularly heavy or light, greasy to the touch, etc., all these points will be quickly perceived and duly regarded.

Then a touch with the point of a knife-blade will show something as to the hardness. This, it must be repeated, should be done carefully so as not to spoil the specimen, and the student must be on his guard not to make any of the mistakes easily possible in such trials, as before pointed out (pages 76, 77). If the mineral is not scratched by the knife it will be well to see whether it will scratch a piece of window-glass, and then whether it is scratched by or will scratch the smooth surface of a quartz crystal—for the number of minerals as hard or harder than quartz is very small, as further stated on p. 357.

At the same time with the test for hardness, the streak, or color of the powder, left by the knife or on a surface of ground glass or unglazed porcelain, must be noticed. Also if, as is most desirable, the blade of the knife is a magnet, the distinguishing character of magnetite and pyrrhotite will show itself at once. The careful determination of the specific gravity requires more time, and may be postponed till the blowpipe has been used, but the hand should have already made a rough estimate of this, as has been before remarked (p. 79 *et seq.*).

Further, when the characters mentioned have all been noted it will be often necessary to make some chemical tests (read carefully pp. 153 to 157). A fragment for examination can generally be obtained by a careful blow with a light hammer without injury to the specimen. This, placed in a test-tube or on a watch-glass, with a little strong hydrochloric (or nitric) acid (p. 155), will effervesce with a nearly odorless gas (carbon dioxide, CO_2) if it is a carbonate. Calcite effervesces at once, even in large fragments, in dilute acid, and other carbonates will act in the same way in strong acid, and also in dilute if they are first pulverized or the tube is warmed (p. 155). But remember that sulphureted hydrogen or hydrogen sulphide (H_2S) may be liberated from a sulphide by warm hydrochloric acid (p. 155), and do not decide a given specimen is *siderite* instead of *sphalerite* hastily because effervescence is observed, and overlook the strong offensive odor of the hydrogen sulphide; in other words, at all times the different senses should act together.

The solution obtained will give the chemist the means of learning more (e.g., the presence of copper, p. 156), and if the specimen is insoluble, even when finely powdered and heated in acid, that is an important point (pp. 156, 157).

The blowpipe tests may come before or after the other chemical examination, and these have been so fully explained in Chapter VI that they need not be repeated here. A careful study of this chapter will have given the student full command of this part of the subject, and his experience should have taught him what order is best for the different tests. He will have learned, for example, that a mineral with metallic luster should first be tried in the open tube. If sulphur is present (the mineral being a sulphide) it will be given off as sulphur dioxide (pp. 149, 150), and at the same time arsenic, antimony, and mercury will show themselves (p. 148 *et seq.*). The closed tube may be taken next and then the charcoal (p. 140), which last will confirm the results already obtained, and also show by the coating the presence of zinc, lead, etc.; also, by adding soda in most cases, the presence of a reducible metal (p. 139) may be proved, as lead, silver, tin; while a magnetic residue will indicate iron. Further, after roasting off (p. 139) the sulphur, arsenic, or antimony the residue may be tested for copper, cobalt, etc., with borax on the platinum wire.

A mineral with unmetallic luster may be tried first in the forceps (but always with caution: it may contain antimony, for example), and the degree of fusibility, the flame coloration, and other phenomena noted (p. 130, *et seq.*), and then an examination made on the platinum wire (p. 136 *et seq.*), in the bead of borax or salt of phosphorus. In the latter a silicate leaves a skeleton of undissolved silica having the form of the individual fragment (p. 140).

Note, finally, that to obtain correct and concordant results the *pure mineral* must be experimented upon. In many specimens two or more species are so closely mixed together that it needs sharp eyes, aided by a magnifying-glass,* to separate them; this is particularly true of metallic minerals. Also many species commonly occur in an earthy mass, or gangue, so that it is difficult to obtain absolutely pure material. In such cases the quartz or clay will often do no harm if its presence is noted and the results interpreted correctly. A fragment of cinnabar is entirely volatile on charcoal or in the tube, but frequently it is associated with a gangue of clay, and then this will of course be left behind; also in such cases a fragment heated in the glass tube often yields water which comes from the nonessential gangue.

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* Every mineralogist should have a pocket magnifying-glass, for even good eyes often need assistance, especially in examining small crystals.

Even if at the commencement it seemed as if very little was known about a specimen, the careful use of the eyes, the hand, and the various tests which may be made in a few minutes will have given a pretty complete table of its characters, and these may be used to fill out the blank list as suggested on page 160. In most cases, unless the specimen is quite rare and unusual, it will be possible to suggest the name of a species with the description of which it is to be compared. Where this method of attack yields no definite result complete determination tables* may be employed, and in the hands of one who is skillful in the use of the blowpipe and in the simple chemical tests they will quite surely make it possible to identify any distinct species.

In order to facilitate the work of determination, and at the same time to emphasize prominent characters of many minerals, the following notes are given. It is intended, as a rule, to mention only the prominent species under each head and those showing the given characters most distinctly; to enumerate all which might be fairly included would deprive the lists of their value.

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* As those given in Brush's Determinative Mineralogy.

1. Crystalline Form.

Cubes.—Fluorite (p. 245) is the common mineral, with unmetallic luster, which is likely to occur in cubes; it is easily recognized further by its octahedral cleavage.

Halite (p. 268), or rock salt, also occurs in cubes, but has cubic cleavage and its slightly sticky feel makes it natural to test its taste, which at once removes all doubt.

Pharmocosiderite (p. 225) is a rare arsenate of iron which also occurs in yellow or greenish cubes; the blowpipe (e.g., on charcoal) shows the presence of both iron and arsenic.

Galena (p. 198), of metallic minerals, is frequently in cubes, and is easily recognized by its cubic cleavage, high specific gravity, and lead-blue color.

Pyrite (p. 213) in cubes is known by its light brass-yellow color, brilliant metallic luster, and hardness; furthermore, the cubes usually show fine lines or striations parallel to one pair of edges (see Fig. 183, p. 213).

There are also some minerals crystallizing in other forms nearly like the cube.

Apophyllite (p. 331) may have a form resembling a cube, though it is really a square prism. This is distinguished by the pearly luster on one face, parallel to which there is easy cleavage, while the four other faces show fine lines or striations in one direction.

Chabazite (p. 336) is often in rhombohedrons not far from a cube in angle. Calcite (p. 247) too, though the common rhombohedron cannot be mistaken for a cube, occasionally takes a form very near it in angle. This form has been called a cuboid. Even quartz (p. 273) appears, though rarely, in forms resembling cubes when the fundamental rhombohedron is present almost alone; the same can be said of hematite (Fig. 192, p. 218). A rare sulphate of aluminium, called alunite (p. 244) (it becomes blue after ignition if moistened with cobalt solution) also occurs in cubelike rhombohedrons.

Cryolite (p. 242), though crystallizing in the monoclinic system, has often a form deceptively like a cube to the eye, and the actual variation from this in angle is not great; it is recognized by its ready fusibility and bright yellow flame (sodium).

Octahedrons.—Fluorite (p. 245) sometimes occurs in octahedrons, though the cube is much more common.

Cuprite (p. 194) often takes this form and is at once told by its red color and streak. Spinel (p. 241) is another octahedral mineral remarkable for its hardness. Alum and diamond (p. 166) are common in octahedrons, but each has other characters by which it is readily recognized.

Among METALLIC species magnetite (p. 219) and franklinite (p. 221) are also often in black octahedrons; but though they look alike, the former is strongly magnetic, the latter only very feebly so if at all; the former has a black streak, while that of the latter is brown. Chromite (p. 221) is another mineral sometimes found in black octahedrons. Pyrite (p. 213) is often in brass-yellow octahedrons, and chalcopyrite (p. 191) sometimes appears in forms resembling them. Galena (p. 198) occasionally occurs in octahedrons.

A number of minerals occur in square pyramids looking more or less like regular octahedrons, as noted below, and occasionally a rhombohedral mineral resembles one; this is true, for example, of some dark colored dolomite crystals from Spain.

Dodecahedrons.—Garnet (p. 300) is frequently in dodecahedral crystals, which are *hard* (unless altered on the outside), and commonly dark red to black in color. Magnetite (p. 219) also occurs in black magnetic dodecahedrons, and sometimes cuprite (p. 194) has this form.

It is to be remembered that, even if the whole crystal cannot be seen, the diamond face with angles of 60° and 120° is very characteristic and rarely belongs to any other crystalline form; moreover the angle between two adjacent faces of a dodecahedron is always 120°.

Trapezohedrons.—Garnet (p. 300) is also often in trapezohedrons; it is easily distinguished from analcite (p. 336), which may have the same form, but whose hardness is only 5–5.5. Further, the rarer mineral leucite (p. 291), found in Vesuvian lavas, is also trapezohedral.

Do not fail to notice that the quadrilateral face of this form is very characteristic and will often make it possible to recognize it when only a small part of a crystal is visible.

Pyritohedrons.—The pyritohedral form is characteristic of pyrite (p. 213), known also by its pale brass-yellow color. Cobaltite (p. 228) has the same form, but it is a rare mineral with a tin-white color; it is an arsenide of cobalt.

Tetrahedrons.—Among minerals with unmetallic luster the tetrahedron is common with zinc blende or sphalerite (p. 233) and the rare minerals boracite (p. 262) and helvite

(p. 303). This is also true of tetrahedrite (p. 193), recognized by its black color and brilliant metallic luster.

Further, chalcopyrite (p. 191) not infrequently occurs in forms called sphenoids, which resemble a tetrahedron closely and only differ a little from it in angles.

Square pyramids are common with zircon (p. 312) and vesuvianite (p. 315), also xenotime (p. 271), octahedrite (Fig. 43, p. 32), wulfenite (p. 203), and a few other rare species. Some of these forms look a little like a regular octahedron.

Square prisms are common with zircon (p. 312), vesuvianite (p. 315), apophyllite (p. 331), scapolite (p. 314). Square tables, often very thin, are characteristic particularly of wulfenite (p. 203); they also occur with apophyllite.

Hexagonal Pyramids.—Quartz (p. 273) is the mineral most often found in hexagonal pyramids, but these usually show the planes of the hexagonal prism also (see figures on pp. 273, 274), and often one set of three alternate planes at one end are larger than the other set, as explained on the pages referred to. What appears to be the same form belongs to witherite (p. 265), but it is really a compound twinning form; it is easily distinguished by its softness.

Corundum (p. 239) also has this form, but is recognized by its hardness and adamantine luster. A scalenohedron sometimes looks like a hexagonal pyramid, but is easily distinguished, as noted below.

Hexagonal Prisms.—Beryl (p. 298) is often in hexagonal prisms; the color is usually green (also blue and yellow), and it is *hard* (H. = 7–7.5). Apatite (p. 254) has nearly the same form and color, but is *soft* enough to be scratched by the knife (H. = 5). The prisms of apatite are often terminated by the planes of a hexagonal pyramid; this is less often observed with beryl. Pyromorphite, mimetite, and vanadinite (pp. 200, 201) are also found in small hexagonal prisms, but the crystals are often bundled together and not seldom hollow or cavernous.

Quartz (p. 273) is often in hexagonal prisms, and these commonly show fine horizontal lines or striations. This form is also shown by the different species of mica (p. 303), but they have other distinctive characters.

Calcite (p. 247) has often this form, sometimes long prisms, or again short six-sided tables; it is soft (H. = 3) and usually has its terminal planes in threes; even if it has only a single flat basal plane, the cleavage on three alternate edges of the prism is characteristic.

Tourmaline (p. 317) is often in hexagonal prisms with three rhombohedral faces at each end; three-sided and nine-sided prisms are also common with tourmaline. The usual color is black.

Willemite (p. 236), the silicate of zinc, also appears in hexagonal prisms.

Trigonal Prisms.—This form is characteristic of tourmaline (p. 317); if the crystals are imbedded in the rock, some of the cross-sections made by fracture will usually show the shape of an equilateral triangle.

It must be noted that an isometric dodecahedron, placed with the line joining the two trihedral solid angles (those formed by three adjoining planes) vertical, has the form of a hexagonal prism with three rhombohedral faces at each end, also meeting at angles of 120° (compare Figs. 104, 105, p. 49).

Aragonite (p. 252) has a form which is often an apparent hexagonal prism, but it is really due to twinning.

Rhombohedrons.—A rhombohedral form, with cleavage parallel to faces making angles of 105° to 107° with each other, is characteristic of calcite (p. 247) first of all, also dolomite (p. 260), siderite (p. 223), rhodochrosite (p. 232). Smithsonite (p. 237) belongs to the same group, but is seldom in distinct crystals.

Chabazite (p. 336) is also often in rhombohedral crystals, but they are near a cube in angle, and it shows no distinct cleavage. The same is true of alunite.

Scalenohedrons.—Calcite crystals (p. 247) are not infrequently complete scalenohedrons (*dog-tooth spar*), or the form may be a hexagonal prism with scalenohedral faces at one end. A scalenohedron, if complete, is at once distinguished from a hexagonal pyramid by its zigzag basal edge, or in any case by the fact that the angle of one set of three alternate terminal edges is greater than that of the other set.

Rhombic Prisms.—The following minerals, among the many orthorhombic species, often show a distinct prismatic habit: topaz (p. 320), staurolite (p. 325); also barite (p. 262) and celestite (p. 266).

The same is true of the following monoclinic species: pyroxene (p. 292), orthoclase (p. 285). More or less slender crystals of prismatic form or aspect occur often with the varieties of amphibole (p. 296) and with epidote (p. 316). Other species might be included here.

Tabular Crystals.—Crystals flattened parallel to one pair of faces are common with barite (p. 262); they are often clustered in divergent groups. This is also true of celestite (p. 266). Something of a similar form is seen with crystals of albite (p. 288).

Acicular Crystals.—Very slender, needlelike crystals, often in radiating groups, are characteristic especially of some of the zeolites, as natrolite (p. 335) and the carbonate, aragonite (p. 252). Both are white, but the latter effervesces in hydrochloric acid. Cuprite (p. 194) sometimes appears in bright red capillary crystals. Of metallic species, stibnite (p. 176) often occurs in groups of radiating acicular crystals. Jamesonite (p. 200), a rare sulphide of antimony and lead, looking much like stibnite, also occurs occasionally in capillary crystals.

Millerite (p. 227) is found in small radiating tufts of slender crystals and in capillary forms resembling a bunch of stiff hairs.

STRUCTURE.

Fibrous.—(*a*) *With Separable Fibers.*—Asbestus, a variety of amphibole (p. 296), and chrysotile (often also called asbestus), a variety of serpentine (p. 328), belong here. The latter contains considerable water and is more silky than the other species. This fibrous character also belongs to a rare mineral called crocidolite (p. 298), which in its unaltered form has a bright blue color.

(*b*) *Fibers Not Separable.*—Of the many species having fibrous varieties the most important are calcite and gypsum, each of which has a variety called satin spar;

also aragonite, barite, celestite, anhydrite, brucite, wavellite.

The following are more commonly COLUMNAR rather than fibrous: amphibole, epidote (and zoisite), sillimanite, tourmaline, natrolite, and several other zeolites; also strontianite and witherite. Cyanite is bladed rather than columnar.

Of metallic species, stibnite is the most conspicuous example of columnar structure.

Radiated.—A radiated and more or less fibrous structure in massive varieties is seen conspicuously in some varieties of the following species: natrolite (p. 335), thomsonite (p. 335), stilbite (p. 337); also amphibole (p. 296), wavellite (p. 243, also Fig. 133, p. 68).

Pyrophyllite (p. 324) and gypsum (p. 256, and Fig. 134, p. 68) also have forms that are made up of radiating or, better, *stellated* plates.

Micaceous.—The micas (p. 303 *et seq.*), muscovite, biotite, phlogopite, etc., separate readily into thin, usually tough, flexible, and often elastic laminæ or leaves.

Clinochlore (p. 311) and some related minerals, commonly green in color, give tough, inelastic laminæ. Some other species give soft, more or less brittle leaves, but cleave in the same way with the micas; this is true of talc (p. 326), brucite (p. 260), and pyrophyllite (p. 324). One variety of gypsum (selenite, p. 256) also separates by cleavage into soft, brittle laminæ, but it is not properly micaceous. Orpiment (p. 174) yields thin, flexible plates of bright yellow color and brilliant luster.

Foliated.—Some of the minerals just mentioned, as talc, pyrophyllite, and orpiment, are foliated rather than micaceous. Graphite (p. 168) and molybdenite (p. 178), among minerals with a metallic luster, are conspicuous for their foliated character.

Mammillary.—A mammillary, botryoidal, or globular surface is often seen with prehnite (p. 331, and Fig. 138, p. 68), calamine (p. 237), smithsonite (p. 237), chalcedony (p. 278, also Fig. 137, p. 68), hyalite (opal, p. 283); hematite (p. 217) may be included, though a reniform surface is for it particularly characteristic (Fig. 139, p. 68). Limonite (p. 222) is often in stalactitic forms (Fig. 140, p. 68); also gibbsite (p. 241) and occasionally marcasite (p. 215).

CLEAVAGE.

Cubic Cleavage.—This is exhibited conspicuously by halite or rock-salt (p. 268); also, among metallic species, by galena (p. 198, and Fig. 143, p. 71).

Anhydrite (p. 258) and cryolite (p. 242) sometimes show cleavage in three directions, which sometimes resembles cubic, though not so in fact.

Octahedral Cleavage.—This is usually very distinct with fluorite (p. 245 and p. 71).

Dodecahedral Cleavage.—This is characteristic of sphalerite or zinc blende (p. 233).

Rhombohedral Cleavage.—This is conspicuous with the species calcite (p. 247, and Fig. 144, p. 72), dolomite (p. 260), siderite (p. 223), rhodochrosite (p. 232).

The *basal cleavage* of the micas (p. 303), chlorites (p. 310), brucite (p. 260), and other species, having on this account a foliated or "micaceous" structure, is an important character. Orpiment (p. 174) has also a foliated structure.

Gypsum (p. 256) yields large thin plates by cleavage.

Topaz (p. 320) has perfect basal cleavage. Pyroxene (p. 292) often shows a basal "parting" resembling cleavage.

The feldspars (p. 284) have cleavage in two directions at right angles to each other, or nearly so. Corundum (p. 239) sometimes shows a rhombohedral "parting" resembling cleavage, in directions inclined about 94° to each other.

Barite (p. 262) and celestite (p. 266) have basal and prismatic cleavage.

Amphibole (p. 296) has prismatic cleavage ($124\frac{1}{2}°$). The scapolites (p. 314) have cleavage parallel to the two square prisms.

Among minerals with metallic luster the following have conspicuous cleavage: graphite (p. 168), stibnite (p. 176).

HARDNESS AND TENACITY. (See pp. 74–78.)

Very soft: having a greasy feel. Here belong talc (p. 326) and pyrophyllite (p. 324); also kaolin (p. 239).

Graphite (p. 168) and molybdenite (p. 178), among minerals with metallic luster, have also a greasy feel and soil the fingers.

Soft: scratched by the nail. Here belong gypsum (p. 256), brucite (p. 260), orpiment (p. 174), sulphur (p. 170), cerargyrite (p. 185), cinnabar (p. 187), also some chlorite.

Further, among minerals with metallic luster may be mentioned: stibnite (p. 176), color lead-gray and luster metallic; argentite (p. 184), sectile, yields silver.

Hard Minerals.—It should be noted that most of the *hard* minerals belong to either the class of the Oxides or that of the Silicates. The sulphides are mostly soft, that is, H. = 4 or below; the exceptions are the minerals of the Pyrites Group, of which the common members are pyrite, marcasite, arsenopyrite (pp. 213–215); these are hard enough (6 to 6.5) to scratch glass. Some related sulphides (and arsenides) of cobalt and nickel have H. = 5 to 5.5.

The Carbonates, Sulphates, Phosphates, etc., are also mostly soft, rarely up to 5. Of the Silicates, those yielding water, like the zeolites, are relatively soft, rarely up to 6.

Again, another distinction partly contained in the above is that minerals of metallic luster are not often hard. The most conspicuous exceptions are the members of the Pyrites Family among sulphides, alluded to in the paragrah above, and hematite, magnetite, franklinite (pp. 217–221) among oxides.

The following minerals are *hard*, mostly falling between 6 and 7:

Prehnite (p. 331).
Epidote and zoisite (pp. 316, 317).
Feldspars (p. 284).
Vesuvianite (p. 315).
Rutile (p. 209).
Cassiterite (p. 207).
Diaspore (p. 240).
Chrysolite (p. 312).
Sillimanite (p. 324).

Further, spodumene (p. 295), axinite (p. 325), iridosmine (p. 183), danburite (p. 321), chondrodite (p. 326); finally, cyanite (p. 324), H. = 5 to 7.25.

The following are *very hard*—hardness equal to that of quartz or greater (H. = 7 or above):

	H.		H.
Quartz (p. 273),	7	Beryl (p. 298),	7.5–8
Garnet (p. 300),	6.5–7.5	Spinel (p. 241),	8
Tourmaline (p. 317),	7–7.5	Topaz (p. 320),	8
Staurolite (p. 325),	7–7.5	Chrysoberyl (p. 242),	8.5
Zircon (p. 312),	7.5	Corundum (p. 239),	9
Andalusite (p. 323),	7.5	Diamond (p. 166),	10

Also the rarer species boracite (p. 262), H. = 7; iolite (p. 322), H. = 7 to 7.5; euclase (p. 299) and phenacite (p. 300), H. = 7.5 to 8.

Malleability.—The minerals which are *malleable* include the native metals (see p. 78); less perfectly so argentite (p. 184), cerargyrite (p. 185): these last are conspicuously *sectile*. The rare silver minerals hessite (silver telluride), petzite (gold-silver telluride), are somewhat sectile.

Talc (p. 326) and orpiment (p. 174) are *flexible;* also some mica and chlorite.

SPECIFIC GRAVITY. (See pp. 79 to 88.)

The importance of the specific gravity as a character in the determination of minerals has been repeatedly insisted upon, and the subject has been so fully discussed on pp. 79 to 88 that to give a list of minerals of conspicuously low or high density would be unnecessary repetition. The student should in this connection read again carefully the pages referred to.

LUSTER.

Metallic.—A metallic luster belongs to all the Native Metals, as gold, silver, copper, etc.; also to many of the Sulphides, as stibnite, galena, pyrite, but *not* to sphalerite, cinnabar, and some few others; finally, to a few of the Oxides, as magnetite, hematite (some varieties), ilmenite, chromite, franklinite. The Silicates, Phosphates, Sulphates, Carbonates, etc., have, with very few exceptions, an unmetallic luster.

Outside of these classes the only minerals having a metallic, or in most cases more strictly a submetallic, luster are a very few rare silicates not described in this work; also the species columbite (and tantalite, p. 224) and wolframite (p. 225), briefly mentioned, and a few others related to them.

It should be noted that all the sulphides having an unmetallic luster (sphalerite, cinnabar, etc.) are *soft.* A hard mineral (H. = 6 or above) having an unmetallic luster is either an oxide or a silicate. There are only one or two rare exceptions (as boracite, H. = 7).

Adamantine.—An adamantine luster (as explained on p. 89) belongs to some *hard* minerals, as diamond, corundum, zircon, cassiterite; also to a number of minerals containing lead, as cerussite, anglesite, and other rarer ones, also cerargyrite, cinnabar, cuprite; further, some light-colored specimens of sphalerite and titanite.

A *metallic-adamantine* luster belongs often to pyrargyrite and some specimens of cerussite and cuprite.

Resinous.—Sphalerite (p. 233) is a striking example of resinous luster; many Phosphates belong in this class.

Vitreous or Glassy.—Quartz, beryl, garnet are familiar examples of vitreous luster; most silicates belong here.

Pearly.—Talc (p. 326) and brucite (p. 260) have conspicuous pearly luster, also pyrophyllite (p. 324) in foliated varieties.

A pearly luster is noted on the basal plane of apophyllite (p. 331), also on the side planes of perfect cleavage of gypsum crystals (p. 256) and those of stilbite (p. 337) and heulandite (p. 338). Barite (p. 262) and celestite (p. 266) often show pearly luster on the basal plane; so, also, some kinds of feldspar. Other minerals belong in this same class.

Silky.—Fibrous gypsum (p. 257) and fibrous calcite (p. 249) (each called satin spar), also asbestus (p. 297) are good examples of silky luster.

COLOR.

(*a*) *Metallic Luster.*

The following lists may be helpful, although it has not been attempted to make them complete:

Silver-white or *tin-white:* Native silver; arsenopyrite, cobaltite, and, further, several rare minerals containing cobalt and nickel; also native antimony, arsenic, tellurium, and some compounds of tellurium, as the tellurides of gold (sylvanite), silver, or lead. The color is often dull on the surface in consequence of tarnish.

Steel-gray: Stibnite, oxides of manganese, as pyrolusite and manganite; native platinum.

Lead-gray: Galena, molybdenite (both bluish). Stibnite is also often lead-gray. Argentite and chalcocite are blackish lead-gray.

Copper-red: Native copper.

Bronze-red: Bornite (with variegated tarnish), niccolite.

Bronze-yellow: Pyrrhotite, millerite.

Brass-yellow: Chalcopyrite, brittle, dissolves in nitric acid. Pale brass-yellow, pyrite; also still paler, marcasite. Millerite (see above) has more of a bronze color.

Gold-yellow: Native gold (malleable).

Black or nearly so: Tetrahedrite, chalcocite, graphite, magnetite, hematite, ilmenite, and sometimes limonite; also (luster submetallic) columbite, wolframite.

The following are conspicuous for the tarnish (often bright-colored) of the surface: Bornite, chalcopyrite, tetrahedrite, hematite, some limonite.

The STREAK is to be noted particularly in the case of some minerals with metallic luster. The majority have a streak which differs but little from black, but it is usually dull, not shining. The streak of hematite is brownish red, of pyrargyrite, cochineal-red. The streak is bright and shining with graphite and molybdenite.

(*b*) *Unmetallic Luster.*

Colorless: Quartz, not cleavable, hard; calcite, if crystallized, shows rhombohedral cleavage, soft; gypsum, very soft. Also cerussite and anglesite, some crystallized varieties of albite, barite, apatite.

White: Many massive minerals, especially the feldspars, quartz, calcite, barite, cerussite, scapolite, several of the zeolites, calamine, talc, meerschaum.

Blue: Azurite, usually dark blue to blackish blue; also sapphire, cyanite, some celestite, lazulite, lapis lazuli. One variety of tourmaline has an indigo-blue color. Amethyst and some fluorite are violet-blue. Some beryl is blue or greenish blue, also amazon-stone. Turquois varies from robin's-egg blue to greenish blue and bluish green. Lapis lazuli is a bright blue. Chrysocolla and some varieties of calamine and calcite belong here, also some more or less rare copper minerals (as chalcanthite and some other sulphates, etc.).

Green.—Emerald-green: This is characteristic of some beryl (emerald), also malachite, dioptase, spodumene (hiddenite); also some other minerals containing copper, most of them not described in this book (as atacamite).

Bluish green: Much beryl, apatite, fluorite, amazon-stone, tourmaline, chlorite, prehnite, calamine, smithsonite, chrysocolla.

Apple-green: Talc, some garnet, chrysoprase, willemite, nickel silicate.

Yellowish green: Some beryl and apatite, chrysoberyl, chlorite, also (*olive-green*) chrysolite, datolite, and some serpentine, vesuvianite, titanite. Epidote is *pistachio-green;* pyromorphite is *grass-green.*

Some varieties of amphibole, pyroxene, also serpentine, are dull *grayish* or *blackish green.* Wavellite has green varieties of several shades. Gahnite is dark green.

Yellow.—Sulphur-yellow: Sulphur, some vesuvianite.
Orange-yellow: Orpiment, wulfenite.
Straw-yellow, also wine-yellow, wax-yellow: Topaz, sulphur, fluorite, cancrinite, wulfenite, vanadinite, willemite, calcite, barite, chrysolite, chondrodite, etc.
Brownish yellow: Much sphalerite, siderite.
Ocher-yellow: Yellow ocher (limonite).

Red.—Ruby-red: Ruby (corundum), ruby spinel, much garnet, proustite, vanadinite, sphalerite.
Cochineal-red: Cuprite, cinnabar.
Orange-red: Zincite.
Crimson-red: Tourmaline (rubellite), spinel, fluorite.
Orange-red: Realgar (to aurora-red).
Scarlet-red: Cinnabar.
Brick-red: Some hematite (red ocher).
Rose-red: Rose quartz, rhodonite, rhodochrosite, erythrite, some scapolite and apophyllite.
Peach-blossom red to lilac: Lepidolite, rubellite.
Flesh-red: Some feldspar, willemite (the variety troostite), some chabazite and stilbite, apatite, less often calcite.
Brownish red: Jasper, limonite, garnet, sphalerite, siderite, etc.

Brown.—Reddish brown: Some garnet, some sphalerite, cassiterite.
Clove-brown: Axinite, zircon, pyromorphite.
Yellowish brown: Siderite, sphalerite, jasper, limonite, goethite, tourmaline.

Blackish brown: Titanite, some siderite, sphalerite.
Smoky brown: Quartz.

Black: Tourmaline, black garnet (melanite); also (mostly greenish or brownish black) some amphibole, pyroxene, and epidote; further, some sphalerite and some kinds of quartz (varying from smoky brown to black); also allanite, samarskite. Some black minerals with submetallic luster are mentioned on page 360.

The STREAK is to be noted in the case of some minerals with unmetallic luster. By far the majority have, even when deeply colored in the mass, a streak differing but little from white. The following may be mentioned:

Orange-yellow: Zincite, crocoite.
Cochineal-red: Pyrargyrite and proustite.
Scarlet-red: Cinnabar.
Brownish red: Cuprite, hematite.
Brown: Limonite.

MAGNETIC PROPERTIES. (See p. 96.)

Magnetite (p. 219) is always *strongly* magnetic, so that a fragment jumps to a good magnet even when separated by a little distance. *Pyrrhotite* (p. 212) is also magnetic, but not so strongly so as magnetite; the test often requires some care and the use of small fragments. Some native platinum (p. 181), especially the variety containing considerable iron, is also magnetic.

The following minerals are slightly magnetic in some varieties: Hematite, franklinite. This seems to be due to an admixture of a little magnetite, for when pulverized a little magnetic powder can be separated.

In general a fragment of a mineral containing iron becomes magnetic when roasted on charcoal or when held in the forceps and heated in a strong reducing flame. Thus pyrite, arsenopyrite, chalcopyrite, yield a magnetic globule on charcoal; also a splinter of iron garnet in the forceps fuses to a black bead which is more or less magnetic.

APPENDIX.

The following list includes the names of the species which it is most important that the young mineralogist should have in his collection; they are printed in SMALL CAPITALS. To these are added, in ordinary type, a number of others which are also important but not quite so much so; they may well be present in the cabinet of the school or academy.

GRAPHITE.
SULPHUR.
Orpiment.
STIBNITE.
Molybdenite.
SILVER.
GOLD in quartz.
An ore of silver.
CINNABAR.
COPPER.
Chalcocite.
Bornite.
CHALCOPYRITE.
TETRAHEDRITE.
CUPRITE.
MALACHITE.
Azurite.
GALENA.
PYROMORPHITE.
Mimetite.
Vanadinite.
CERUSSITE.
Anglesite.
Wulfenite.
CASSITERITE.
Rutile.
PYRRHOTITE.
PYRITE.
MARCASITE.
ARSENOPYRITE.
HEMATITE.
MAGNETITE.
Franklinite.
Chromite.
LIMONITE.
SIDERITE.
Columbite.
MILLERITE.
Niccolite.
Garnierite.
Manganite (or Pyrolusite).
RHODONITE.

Rhodocrosite.
SPHALERITE.
Zincite.
Willemite.
Calamine.
SMITHSONITE.
CORUNDUM.
Spinel.
Cryolite.
FLUORITE.
Wavellite.
CALCITE (several varieties).
ARAGONITE.
APATITE.
Anhydrite.
Brucite.
GYPSUM.
DOLOMITE.
BARITE.
Witherite.
CELESTITE.
Strontianite.
HALITE.
QUARTZ (several varieties.)
OPAL.
ORTHOCLASE.
ALBITE.
Oligoclase.
Labradorite.
PYROXENE (several var.).
Spodumene.
AMPHIBOLE (several var.).
BERYL.
GARNET.
MUSCOVITE.
BIOTITE.
Lepidolite.
Clinochlore.
Chrysolite.
Zircon.
Scapolite.
Vesuvianite.
EPIDOTE.
Zoisite.
TOURMALINE.
Topaz.
Titanite.
Andalusite.
Cyanite.
STAUROLITE.
TALC.
SERPENTINE.
Datolite.
PREHNITE.
APOPHYLLITE.
Pectolite.
NATROLITE.
Analcite.
CHABAZITE.
STILBITE.
Heulandite.

If the student limits himself to *small* specimens, as advised on page 13, a collection including the species mentioned will not occupy a great deal of space, and, if desired, can be purchased at no great cost. From time to time additional specimens can be obtained by exchange or purchase.

Of the minerals in the above list the following are most desirable for the blowpipe and other chemical trials described in Chapter IV. Suitable fragments, of the needed purity, can be obtained for a very small expenditure of money.

Stibnite, molybdenite, an ore of silver, cinnabar, chalcopyrite, tetrahedrite, cuprite or malachite, galena, pyromorphite, cassiterite, rutile, pyrite, arsenopyrite, hematite or siderite, millerite, rhodonite, sphalerite, corundum, cryolite, fluorite, calcite, apatite, brucite, barite, celestite, orthoclase, amphibole (actinolite), garnet (almandite), tourmaline, natrolite.

Also in addition to these: a mineral containing lithium, as either lepidolite, spodumene, amblygonite, or triphylite; one containing cobalt, as linnæite; chromium, as chromite or crocoite; vanadium, as vanadinite; uranium, as uraninite (pitchblende) or autunite.

It is further convenient to have suitable specimens of the first eight or nine minerals in the scale of hardness (p. 75).

For those who wish to learn more about minerals than is given in this very elementary work, the *Manual of Mineralogy* (4th edition, 1887), by James D. Dana, may be recommended. This may be followed by the *Text-book of Mineralogy* by the present author, in which the subjects of crystallography and physical mineralogy are discussed from a more advanced standpoint. *Dana's System of Mineralogy*, 6th edition, 1892 (1134 pages, large 8vo, with Introduction, i to lxiii), is devoted exclusively to the descriptions of species, which are given with great fullness. The above works are published by John Wiley & Sons, New

York. Two volumes by Bauerman, one upon Systematic Mineralogy and the second on Descriptive Mineralogy, also deserve to be mentioned (Longmans, Green & Co., London and New York). Further, the following small and inexpensive volumes: A brief pamphlet entitled *First Lessons in Minerals*, by Ellen H. Richards, 50 pp. 12mo, Boston, 1889; *A Course of Mineralogy for Young People* (in three grades), by Gustave Guttenberg, Pittsburg, Pa. (Agassiz Association Course); *Common Minerals and Rocks,* by William O. Crosby, Boston, 1881 (Guides for Science Teaching, No. XII).

In determinative mineralogy and blowpipe analysis the Manual by Professors G. J. Brush and S. L. Penfield (John Wiley & Sons) will be found very satisfactory. The *Elements of Crystallography,* by G. H. Williams (Henry Holt & Co., New York), is an excellent work.

It may be a convenience to students and schools to have the following addresses of dealers in minerals:

Rochester: Ward's Natural Science Establishment, 76 College Avenue.

Philadelphia: Foote Mineral Co., 107 N. Nineteenth St.

Washington: E. E. Howell, 612 Seventeenth Street, N. W.

New York City: A. H. Petereit, 81 Fulton St.

Other addresses are given in the *Mineral Collector*, published monthly by Arthur Chamberlain (333 W. 41st Street), New York City.

Blowpipe apparatus can be obtained from Eimer & Amend, 205 Third Avenue, New York City. They are also agents for Dr. F. Krantz in Bonn, Germany, the dealer in minerals, fossils, etc., who makes excellent models of crystals in wood and pasteboard. Apparatus can be also obtained from James W. Queen & Co. of Philadelphia.

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